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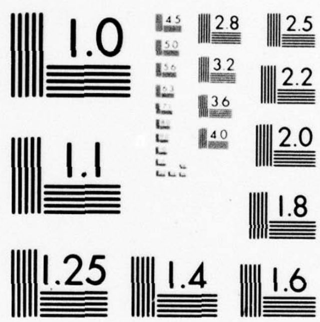


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# Environmental Impact Analysis Process

FINAL
ENVIRONMENTAL IMPACT STATEMENT

OPERATION OF THE PAVE PAWS RADAR SYSTEM
AT OTIS AIR FORCE BASE, MASSACHUSETTS

Part 1: Basic EIS & Appendices

MAY 1979

DEPARTMENT OF THE AIR FORCE

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The Final EIS contains markings in the margin to indicate the text that was amended from the Draft version. A plus (+) sign indicates lines that are revised or deleted, and a double plus (++), used once at the beginning of revised text, indicates that major revisions were made for a whole section, a paragraph or portion of a paragraph, or a table or figure. ++

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18. SUPPLEMENTARY NOTES

This document consists of two parts. Part 1 contains the basic EIS and its technical appendices. Part 2 (the attachment to the EIS) contains the public hearing transcript, the public and agency comments on the Draft EIS, and the Air Force responses to the comments.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

PAVE PAWS (Phased Array Warning System)
Environmental Impact Statement (EIS)
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AN/FPS-115

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Final Environmental Impact Statement (EIS) discussing the effects of operating the PAVE PAWS (Phased Array Warning System), a new sea-launched ballistic missile surveillance and tracking radar system, at Otis Air Force Base on Cape Cod, Massachusetts. The EIS addresses the potential environmental effects on human health, land use, demographics and economics, and electromagnetic interference. Alternatives are considered along with unresolved issues. The conclusions are: (1) At the PAVE PAWS power levels (i.e., average — cont

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Block 20 Abstract (continued)

power density exposures for the general public at the sub-microwatt/cm$^2$ level even with implementation of a possible "growth" option) there is no hazard to humans, other fauna, or flora from the radiofrequency radiation; (2) Only minor effects on land use, demographics, and economics are expected; and (3) Electromagnetic interference is either minor or can be satisfactorily reduced. In summary, the EIS states that operating the PAVE PAWS at Flatrock Hill on Otis Air Force Base will have no significant environmental impact.

The EIS contains an in-depth, critical review of the present state of knowledge regarding biological effects of radiofrequency radiation. The review was based primarily on the selection and analyses of documents, from the large body of literature on the subject, that are most significant scientifically and pertinent to the operational characteristics of PAVE PAWS and to the power densities of radiofrequency radiation in the geographical region around the radar. The bibliography includes 269 citations.

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## Preface

In response to requests made by residents of Cape Cod communities, members of the Massachusetts Congressional Delegation, and State Officials, the Air Force, since the spring of 1978, has voluntarily undertaken to provide a further study of the environmental effects of the PAVE PAWS radar facility. This study has been prepared in the format and according to the procedures used for an Environmental Impact Statement (EIS).

The Air Force contracted with SRI International (Contract #F08635-76-D-0132-0008) to provide inputs to this EIS. ++

The principal participants in the project at SRI International were the project leader, Dr. Ronald K. White, Program Manager and physicist; Dr. Marilyn K. Bland, Senior Ecologist, biology; Dr. Buford R. Holt, Senior Ecologist, botany; Ms. Susan J. Mara, Senior Resource Analyst, geology; Ms. Tracy H. Walklet, Resource Analyst, Land Use; Ms. Kristin M. Clark, Research Analyst, pollutants; Ms. Leslie A. Young, Research Analyst, socioeconomics; Mr. John W. Ryan, Program Manager, socioeconomics; Dr. William A. Edson, Staff Scientist, radar fields; Mr. Ronald I. Presnell, Senior Research Engineer, radar fields; Mr. Richard A. Shepherd, Senior Research Engineer, electromagnetic interference; Mr. Bruce C. Tupper, Senior Research Engineer, electromagnetic interference; Dr. Peter Polson, Senior Biomedical Engineer, bioeffects; Dr. John S. Krebs, Senior Biophysicist, bioeffects; Dr. David C. Jones, Director, Toxicology Laboratory, bioeffects; Mr. Louis N. Heynick, Staff Physicist, bioeffects. ++

Throughout the environmental impact analysis process, the documents were reviewed by members of the following Air Force organizations: Office of the Secretary of the Air Force; Headquarters, U.S. Air Force; Headquarters, Air Force Systems Command; Headquarters, Aerospace Defense Command; Electronic Systems Division; Aerospace Medical Division; and USAF School of Aerospace Medicine. ++

The Draft EIS was amended in response to public and agency comment to produce this Final EIS. A transcript of a public hearing on the Draft EIS, copies of other public and agency comment, and responses to comments are provided in a separate attachment to this Final EIS. ++

## SUMMARY

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### FINAL ENVIRONMENTAL IMPACT STATEMENT (EIS)

### Operation of the PAVE PAWS Radar System at Otis Air Force Base, Massachusetts

<u>Description of the Action</u>

PAVE PAWS is a new surveillance and tracking radar operated by the U. S. Air Force (USAF). Its primary purpose is to detect, track, and provide early warning of sea-launched ballistic missiles. PAVE PAWS maintains a long-range, wide-area coverage utilizing phased array techniques. The substantially improved missile detection and tracking capability that it will provide is essential to characterize adequately a sea-launched ballistic missile attack and to provide earlier warnings to strategic forces. The secondary purpose of PAVE PAWS is to assist the USAF SPACETRACK System by tracking objects that are orbiting the earth.

The first PAVE PAWS installation is located at Otis Air Force Base (AFB), Barnstable County, Massachusetts. With the PAVE PAWS in operation, older radars at Fort Fisher Air Force Station (AFS), New Hanover County, North Carolina, and Charleston AFS, Penobscot County, Maine, will be retired. PAVE PAWS is expected to operate continuously at Otis AFB for at least 10 years. Environmental impacts of other PAVE PAWS installations are not addressed in this EIS.

PAVE PAWS is housed in a large main building with associated facilities on a site of approximately 4 acres. An additional 6 acres are used for an access road and 50 acres are fenced and posted to prevent humans and some animals from approaching close to the radar face. A total of approximately 200 operating and maintenance personnel are required. Deactivation of the radars to be replaced will reduce manpower requirements by a total of 105 positions.

The PAVE PAWS is designed to accommodate a potential power increase. However, approval has not been given to incorporate such enhanced capability, i.e., the growth option.

<u>Environmental Effects</u>

<u>Human Health</u>. Radiation safety is of paramount importance. The environmental analysis in this area includes an in-depth, critical review of the available literature on the subject, extensive calculations of worst case predicted signal levels, and measurement of actual radiation levels under conditions representative of the maximum signals during full-scale operation.

The literature review addresses the present state of scientific knowledge regarding the biological effects of radiofrequency radiation (RFR) in the range of 10 to 18,000 MHz. The documents judged both most significant scientifically and most relevant to the operational characteristics of PAVE PAWS and the anticipated electromagnetic radiation power densities were selected from the large body of available literature. The hundreds of research studies reviewed indicated many different RFR-induced biological effects, but only at radiation levels much greater than those to which the general public will be exposed by PAVE PAWS.

For the general public, long-term exposures for persons in the communities surrounding Otis AFB should be less than 0.03 microwatts/cm$^2$. Neither climatic conditions, time of year, nor even the growth option should increase this actual long-term exposure beyond 0.06 microwatts/cm$^2$.

The nearest point of ready approach to PAVE PAWS on the ground is the Route 6 rest stop which is 3450 ft from the radar. At that point, the measured average power density was 0.06 microwatts/cm$^2$. Measured pulse power density was 20 microwatts/cm$^2$. Even if the growth option should be implemented, actual average power density should not exceed 0.12 microwatts/cm$^2$. If persons enter Otis AFB and cross the military reservation to reach the PAVE PAWS 1000 ft exclusion fence, the average power densities should not exceed 30 microwatts/cm$^2$ even with the growth option. At the security fence, the maximum average power density is calculated to be 90 microwatts/cm$^2$ with the basic system and 160 microwatts/cm$^2$ with the growth option. Actual values are expected to be lower. The airborne exposure situation was thoroughly evaluated. The conclusion is that there is no biological hazard even with the growth option.

No scientific evidence was discovered to indicate that any ill effects will result from long-term exposure to the PAVE PAWS emissions. The relatively few retrospective epidemiology studies of health effects from RFR exposure done in the United States and the USSR are not considered evidence that the PAVE PAWS emissions will constitute a hazard to the population. Also, there is no clear experimental evidence that exposure of animals to the PAVE PAWS average and pulse power densities results in any biological hazards. The general public exposure from PAVE PAWS is far lower than any existing or proposed safety standard. PAVE PAWS should not be affected by any new environmental standard.

The inherent safety of PAVE PAWS has been supported this year by several other reviewers. The National Academy of Sciences concluded that "it is improbable that exposure will present any hazard to the public." The National Telecommunications and Information Administration concluded "there is probably no environmental hazard." Similarly, the Environmental Protection Agency stated "PAVE PAWS radiation is unlikely to cause health effects in the general population of the area where prolonged exposure is expected".

Electromagnetic Interference. Some interference with TV reception; aircraft, mobile, and ham radios; and other electronic equipment in the area is possible. In most cases this interference should not be disruptive; in others, it could be reduced by adjustments to the equipment or possibly by changes in the operation of the PAVE PAWS radar.

People with cardiac pacemakers are very unlikely to be affected outside the fenced "exclusion zone" on the ground or in the air.

Land Use. No significant effects on land use are anticipated. When operation of PAVE PAWS ends, the 50 fenced acres could be returned to their prior use as wildlife habitat. However, as the structures may not be removed, the loss of 10 acres of wildlife habitat may result for an indefinite period.

Population and Economics. The expected demographic and economic effects of PAVE PAWS are minor. The changes in the population at and around the affected USAF installations will be very small compared to historical changes in the areas.

## Alternatives Considered

No Action. PAVE PAWS would not be operated at Otis AFB, and operation of radars that it is scheduled to replace would continue.

Postpone Action. Full-scale operation of PAVE PAWS would be postponed to allow the resolution of specific problems or issues related to PAVE PAWS operation.

Different Location. The PAVE PAWS facility now built at Flatrock Hill would be removed and reconstructed at one of three other sites: Pine Hill (also within Otis AFB); North Truro, Massachusetts; or a shoreline platform extending offshore.

Modify the Radar or Its Surroundings. To minimize interference, certain frequencies would not be used during PAVE PAWS operation. Earthen berms and sheet metal or wire screens would be used to shield specific areas.

Conclusion. Operating PAVE PAWS at Flatrock Hill on Otis AFB will have no significant environmental impact. The possibility that new information would reveal a significant environmental impact has not been dismissed, but is judged to be unlikely.

## Public Concerns and the Air Force Response

Some common concerns expressed in the comments on the Draft EIS related to: (1) the reliability of the radar's beam control procedures; (2) the perceived bias in the scope and analysis of the information on bioeffects mechanisms and on other possible bioeffects; (3) the need for additional radiation and public health monitoring; and (4) the lack of absolute proof concerning the safety of RFR at the PAVE PAWS power densities (i.e., general public exposure at the sub-microwatt/$cm^2$ level).

The following is an overview of the USAF position with regard to the common concerns listed above:

(1) The triple-redundant procedures which control the positioning of the radar beam are adequate and secure. The control reliability has also been independently verified by the National Academy of Sciences.

(2) The text has been revised to eliminate what was perceived as bias in the Draft EIS. The EIS presents a balanced view of the state-of-knowledge of the bioeffects possible from operation of PAVE PAWS.

(3) Additional continuing radiation monitoring would not serve a useful purpose because the radar can not expose the public to higher levels of radiation than are described in the EIS. Public health monitoring would not serve a useful purpose because general public exposure from PAVE PAWS will be in the sub-microwatt/$cm^2$ range even if the growth option is implemented.

(4) Absolute proof of safety is not possible; however, the EIS represents a thorough evaluation of the potential environmental impact of operating PAVE PAWS and, at the PAVE PAWS power densities, no hazard is predicted from either the basic or growth systems. This conclusion has also been reached by the National Academy of Sciences.

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## Chapter 1

## INTRODUCTION

### 1.1 Project Description

PAVE PAWS (i.e., Phased Array Warning System) is a new surveillance and tracking radar system operated by the U.S. Air Force (USAF). The primary purpose of this radar is to detect, track, and provide early warning of sea-launched ballistic missiles launched against the continental United States from the ocean, but it will also assist the USAF Spacetrack System by tracking objects in earth orbit.

The first PAVE PAWS is located at Otis Air Force Base (AFB), Massachusetts (see Figure 1-1). Operation of this facility by the USAF Aerospace Defense Command (ADCOM) will permit deactivation of older radars at Fort Fisher Air Force Station (AFS), North Carolina, and Charleston AFS, Maine. Other surveillance operations carried out at Ft. Fisher AFS by ADCOM will continue. This environmental impact statement (EIS) discusses the effects of operating PAVE PAWS at Otis AFB and discontinuing the operations that PAVE PAWS will supersede at the two AFSs. (A second PAVE PAWS site at Beale AFB, California, will be addressed in a separate EIS.)

Most of the PAVE PAWS radar system is contained in a building 105 feet high and approximately 100 feet by 150 feet at its base (see Figure 1-2, p. 1-3). Five floors house radar equipment, maintenance areas, office space, and a cafeteria. Figure 1-3, p. 1-4, shows other facilities on the approximately 4-acre site, including an access road, parking areas, a gatehouse, fuel storage, fencing, and utilities (i.e., facilities for water supply and distribution, electric power generation and distribution, and sewage and waste water treatment and disposal). A zone extending about 1,000 feet from the radar is fenced (6 ft chain-link exclusion fence) and posted to prevent humans and some animals from inadvertently approaching too close to the radar beam. A security fence (9 ft chain-link fence with barbed wire) surrounds the buildings and other facilities. A perimeter detection system, to be buried just outside the security fence, will signal the presence of any intruder to the guards.

Current plans call for PAVE PAWS to operate continuously for 10-20 years. A total of approximately 200 operating and maintenance personnel are required, about half of whom are civilian employees. This total includes administration and management personnel as well as staff for three shifts. During the first

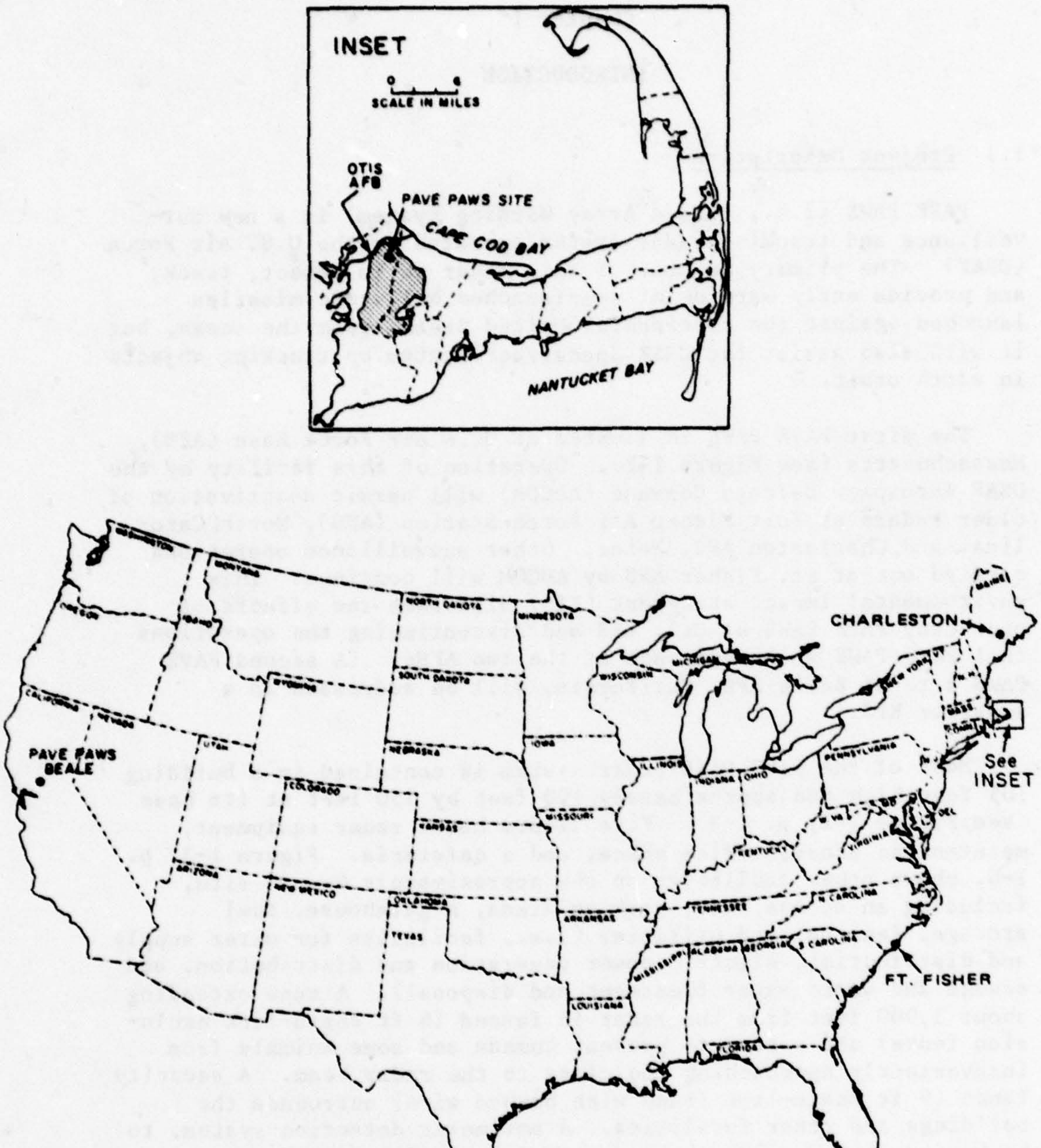
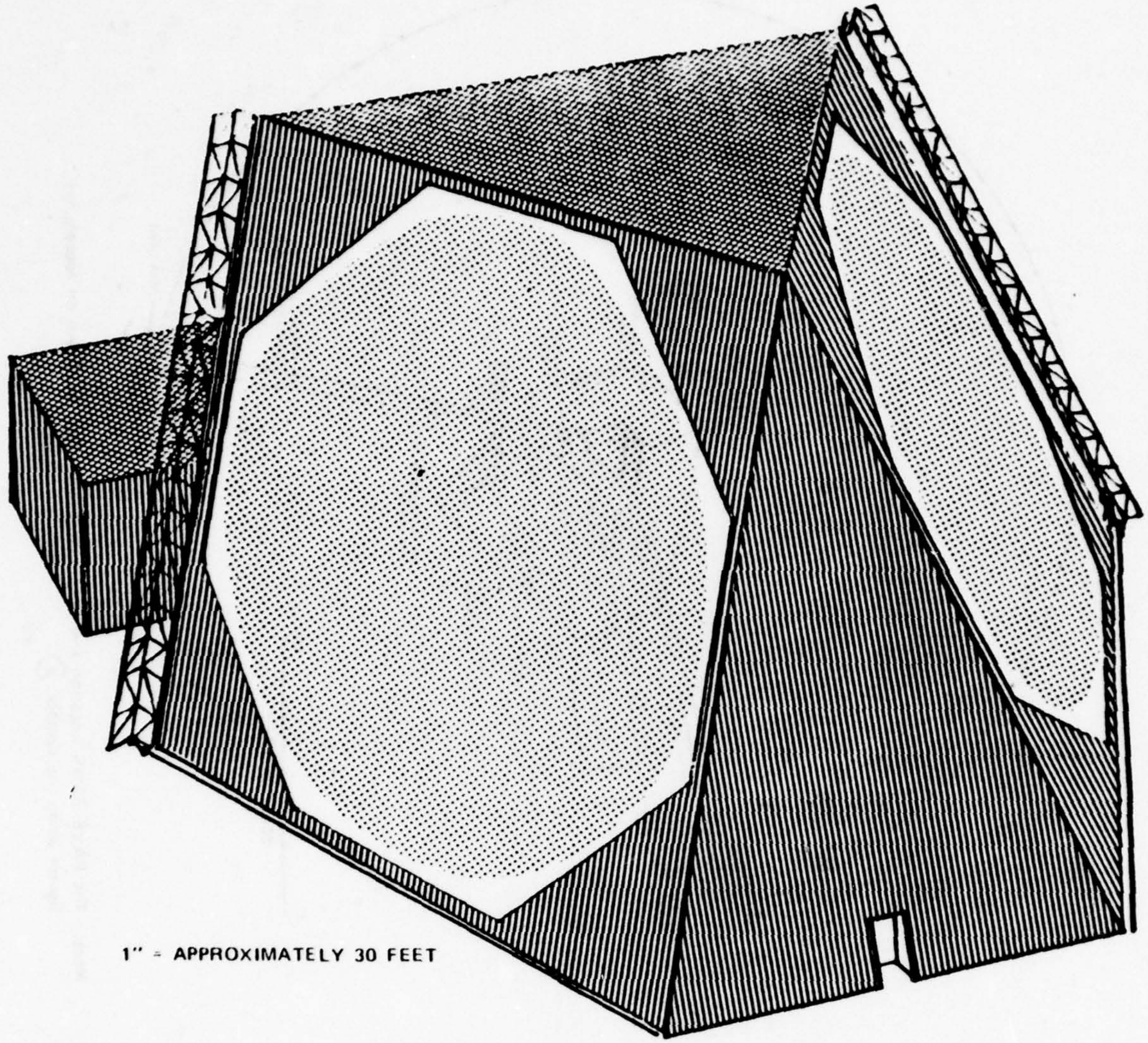
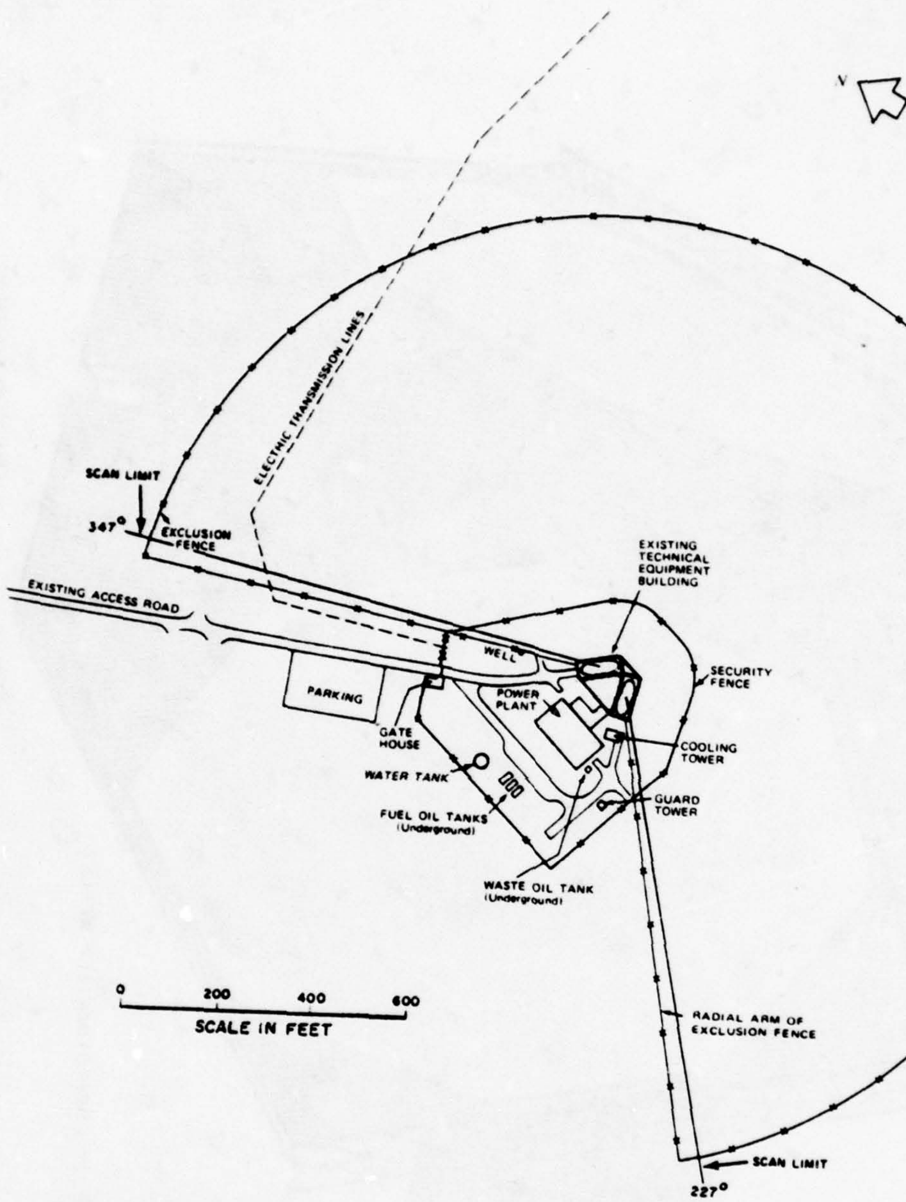



FIGURE 1-1. OTIS AIR FORCE BASE, FORT FISHER AND CHARLESTON AIR FORCE STATIONS



1" = APPROXIMATELY 30 FEET

FIGURE 1-2. PAVE PAWS RADAR AND POWER PLANT BUILDINGS




Note: The PAVE PAWS Location and Scan Limits will often be shown on subsequent figures using the symbol:

FIGURE 1-3. PAVE PAWS SITE PLAN

year of operation, an additional 90 to 100 people will be trained to operate the PAVE PAWS facility at Beale AFB, California.

As shown in Figure 1-2, p. 1-3, the main building is roughly triangular in shape. Rather than a rotating dish-shaped antenna, the PAVE PAWS antennas are two flat antenna arrays that make up two walls of the main building. The two walls form a 60 deg angle and are tilted back 20 deg from the vertical. When operating, each antenna array forms an electromagnetic beam.

Each array is composed of 5,354 individual antenna elements, of which 1,792 (3,584 in a "growth system" option) are electrically activated. During operation, a prescribed electric current delivered to these elements generates local electric and magnetic fields. Spreading and merging of the fields from the many elements creates the radar beam. The radar may operate at any of 24 specific frequencies between 420 and 450 megahertz (MHz). By way of reference, this range is located just below frequency bands used in such mobile land communication systems as fire, police, and taxi radios. +

Each antenna array broadcasts electromagnetic radiation (EMR) throughout a hemisphere centered on the array face. (Appendix A contains a detailed description.) Three EMR regions having distinct characteristics are created: (1) the near field, less than about 600 feet from the antenna array; (2) the transition zone, between about 600 and 1,450 feet; and (3) the far field, beyond about 1,450 feet. (Those distances are approximately doubled for the growth system.) The EMR environment in all regions is very complicated, but its important features can be described simply. In the near field, nearly all of the radiated power appears in a well-defined portion of the hemisphere, approximately a cylinder. At the edge of this cylinder, the power density (i.e., the amount of power per unit of cross-sectional area in microwatts/cm$^2$) is about 1/10 of the power density at the beam axis. (In this EIS, the term power density is used to mean time-average power density, in contrast to the power density of a single pulse.) Therefore, the radar beam in the near field can be described as a cylinder centered on the array (see Figure A-1, p. A-4). + +

In the transition zone, the EMR field evolves into a pattern which in the far field resembles a set of cones. The main beam occupies the innermost cone within 2.6 deg (1.8 deg for the growth system) of the direction in which it is aimed (see Figure 1-4 and Figure A-1, p. A-4). The remainder of the hemisphere contains sidelobes, the first of which occupies a hollow cone centered on the main beam (see Figure 1-4). The higher order sidelobes are individual, irregularly shaped cones distributed in a pseudorandom fashion throughout the hemisphere. In the far field, about half of the radiated power is concentrated in the main radar beam; the remainder appears in the sidelobes. However, the power density of the sidelobes is at most 1/100 (first sidelobe) to 1/1,000 +

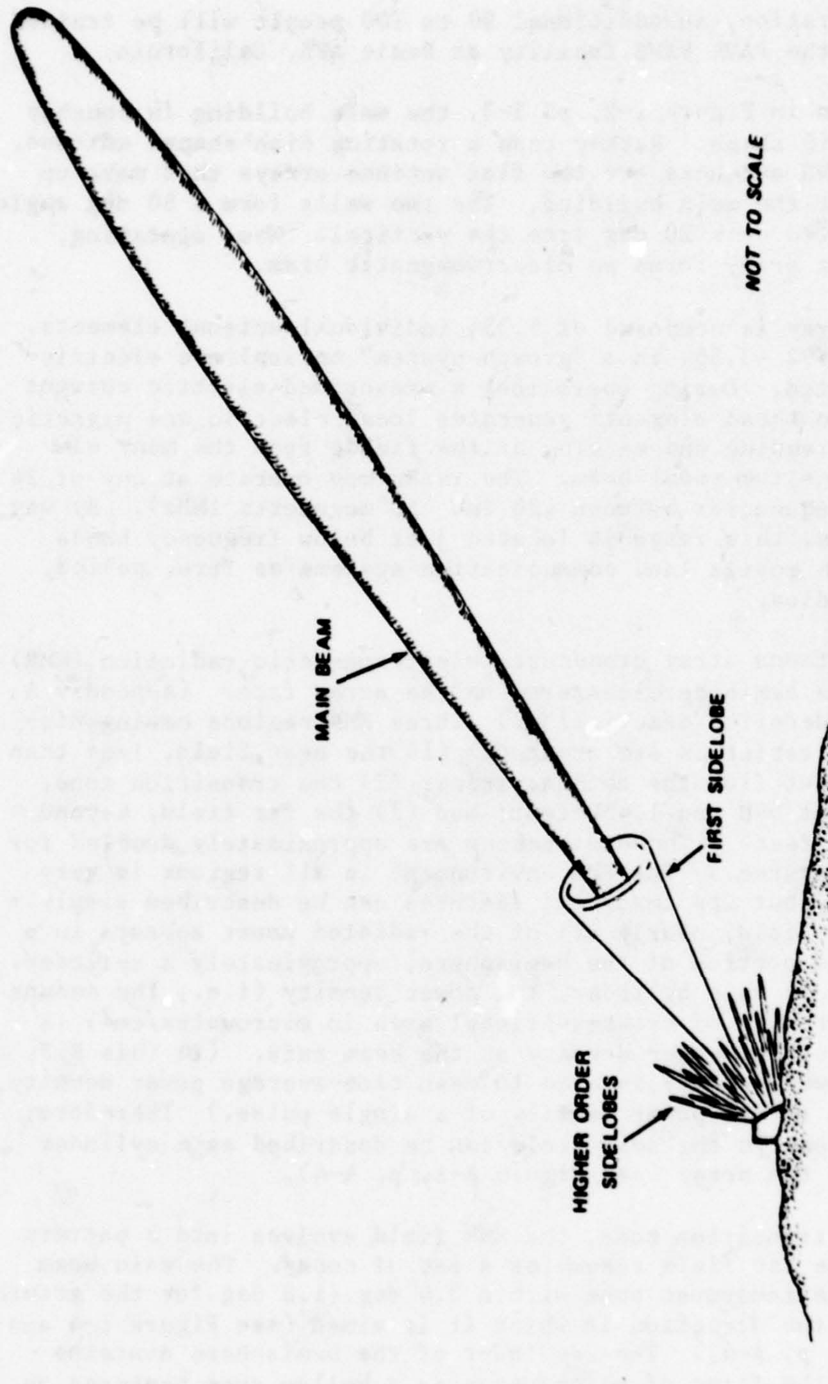



FIGURE 1-4. ARTIST'S SKETCH OF PAVE PAWS EMR PATTERN

(higher-order sidelobes) of the main beam power density. Because power densities a relatively few degrees away from the beam axis are such small fractions of the main beam power density, the PAVE PAWS radar beam is functionally a highly focused, narrow beam of radiation.

Neither the main beam nor the sidelobes radiated by the antenna array occupies the entire hemispheric volume at all times. The radar beam is actually a series of electromagnetic pulses whose characteristics are prescribed by surveillance and tracking requirements. Thus, the beam is intermittent rather than continuous. PAVE PAWS will transmit only about 18% of the time, and will receive reflected EMR during the remaining 82%. (Section D.2, p. D-4, contains a detailed description.)

Each radar beam can be "steered" or pointed electronically 3 deg to 85 deg above the horizontal. It can also be steered as much as 60 deg to the left or right (that is, $\pm 60$ deg in azimuth), for a total of 240 deg of azimuth coverage by the two antenna arrays (see Section A.2.3, p. A-2). The radar beams can search for or track objects as much as 3,000 miles away. To detect sea-launched ballistic missiles, the radar beams will scan continuously through their azimuth range at 3 deg above the horizontal (although the scanning elevation may occasionally be raised to as much as 10 deg above the horizontal). One antenna face points northeast and the other points slightly east of south. Therefore, the scanning will range from 347 deg to 227 deg by the compass, or roughly from north-northwest through north, east, and south to southwest. For satellite or missile tracking, the radar beams will be pointed as much as 85 deg above the horizontal. The scanning action of the radar beams will be so rapid that any given point will be "in" the main beam for only a fraction of a second at about 1.4-second intervals. However, points not "in" the main beam are exposed to the low-level sidelobe EMR during each pulse.

The basic PAVE PAWS system is designed to permit the inclusion of a potential power increase. However, although the potential improvements have been defined and identified as the "growth system," approval has not been given for incorporating them into the system. The primary improvements would be an increase in radiated power and a narrower main radar beam. All other principal parameters would remain the same. In any case, this EIS fully addresses the environmental impacts of the growth as well as the basic system.

## 1.2 Existing Site Characteristics

### 1.2.1 Otis AFB, Massachusetts

Otis AFB (see Figure 1-5), located on land owned by the State of Massachusetts, is currently used by the U.S. Coast Guard, the Massachusetts Air National Guard, the Massachusetts Army National

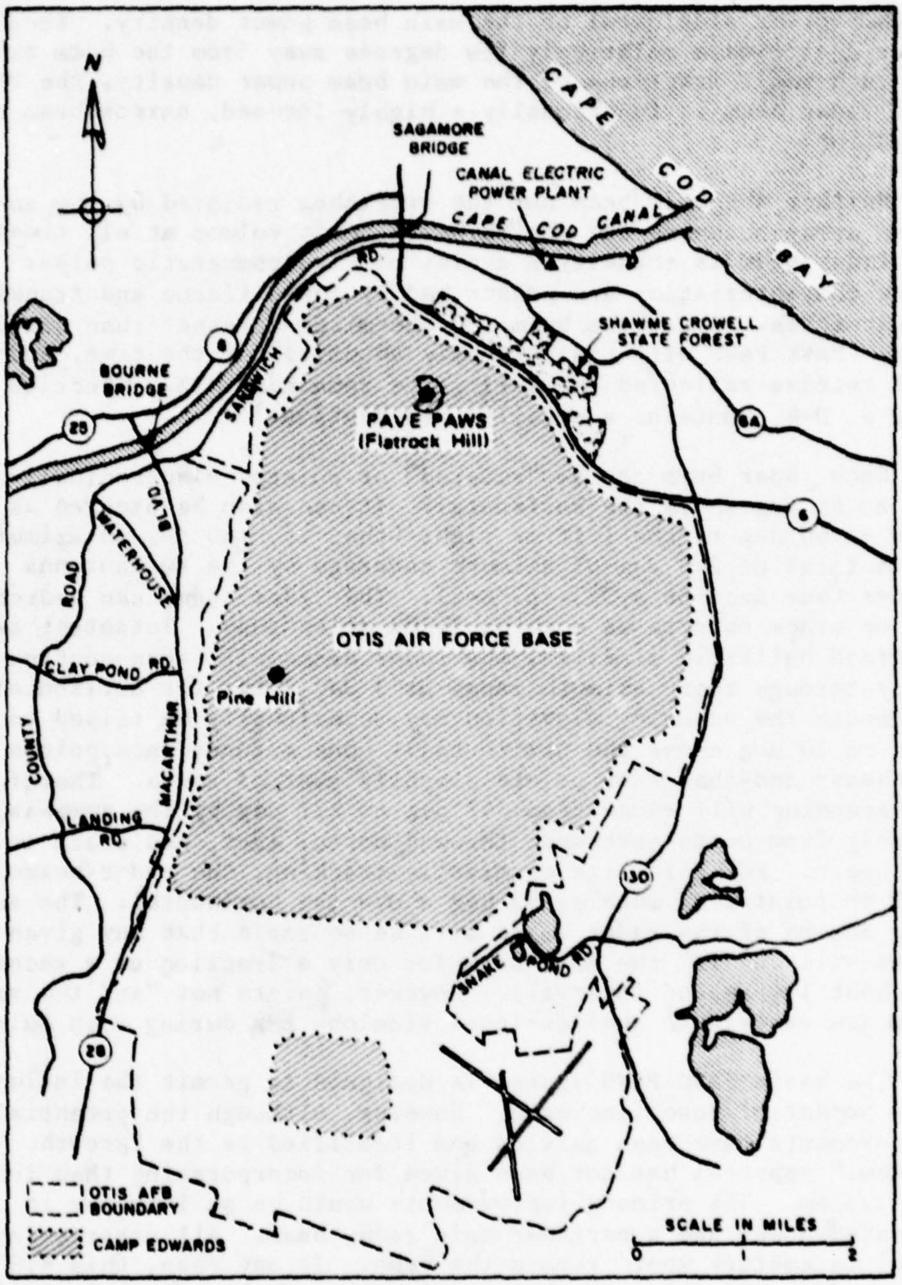



FIGURE 1-5. OTIS AIR FORCE BASE

Guard, and ADCOM. The total military reservation, including Camp Edwards, consists of approximately 20,000 acres, much of which has remained relatively undeveloped. In the recent past, the base has undergone several periods of transition. In mid-1970, the Coast Guard moved its Air Station from Salem, Massachusetts to Otis. Then, during 1973, some of the Air Force's activities at Otis were discontinued. (A more detailed discussion of the base, as well as ongoing activities there, is found in Section 1.2.1.2, p. 1-15, Socioeconomic Characteristics.)

### 1.2.1.1 Biophysical Characteristics

#### 1.2.1.1.1 Plants and Animals

1.2.1.1.1.1 Plants. The original forests of Cape Cod were cleared in the early years of the area's settlement. The present woodlands on the Cape are comprised of a relatively few hardy species which have tolerated repeated cutting, drought, wind erosion and other storm damage, as well as fires at intervals of two to three decades or less. The woodlands on the sandy coastal plains of the Cape, technically characterized as edaphic subclimax forests, have maintained their integrity largely because of recurring fires.

Vegetation cover type maps of the Cape were prepared in 1951 and 1971 at a scale of 1:24,000 (MacConnell, 1973). The predominant vegetation of the wooded areas in this region has continued to be pitch pine (*Pinus rigida*) and scrub oak (*Quercus ilicifolia*) in varying proportions. During the twenty year period spanned by the maps, approximately 20,000 acres of forest land were cleared, and in 1971, approximately 156,000 acres of forest land remained on Cape Cod (MacConnell, 1972; 1974).

According to the Southeast Wildlife District of the Massachusetts Division of Fisheries and Game, the 17,000 acres of natural habitat currently at Otis Air Force Base is one of the largest blocks of woodland remaining on the Cape. The vegetation at, and in the immediate region of, the PAVE PAWS site at Flat Rock is typical of the forested areas at Otis AFB and the Cape. It consists of unbroken tracts of woodland dominated by oaks and pitch pine approximately 50 feet high, with a generally continuous shrub layer comprised largely of blueberries and other heaths about 1.5 ft high.

Most of the woody species at Otis AFB are widely distributed throughout the eastern United States. None of the woody or herbaceous species reported is federally listed as threatened or endangered (U.S. Fish and Wildlife Service, 1976). The Commonwealth of Massachusetts does not presently have a state listing of threatened and endangered flora (personal communication with Chet McCord, Massachusetts Division of Fisheries and Wildlife).

Herbs are infrequent within the relatively undisturbed woodlands at Otis; however, the more recently disturbed sites contain rich stands of native and introduced species, with a typical herbaceous community containing 30 to 50 species. These plant species are characterized by a strong representation of grasses, sedges, asters, goldenrods, and other species characteristic of roadsides, vacant lots, and other ruderal areas. No rare herbaceous plants have been reported for Otis AFB.

The major economic value of the project site and the surrounding area is its recreational use. Additional information on the specific vegetation of the Cape can be found in Hinds (1968).

1.2.1.1.1.2 Animals. The 17,000 acres of natural habitat at Otis AFB provides suitable habitat for white-tailed deer and several other species of wildlife. According to the Southeast Wildlife District Division of Fisheries and Game, the natural habitats at and near Otis AFB comprise the last large block of deer range remaining on the Upper Cape which have not been subjected to extensive human influence. The Otis AFB Wildlife Management Area is located on 3,000 acres at the northern end of the base (see Figure 1-6, p. 1-16). It is opened briefly each year (approximately one week) for public hunting. A wildlife corridor located on the western side of the base connects this area to the Crane Wildlife Management Area which borders the base to the south.

A wildlife agreement exists between the Massachusetts ++
Department of Fisheries and Wildlife (now called the Department of Fisheries, Wildlife, and Recreational Vehicles, Division of Fisheries and Wildlife) and DoD, entitled "Cooperative Plan for Civilian Hunting on Otis Air Force Base, Massachusetts," and dated 17 October 1966. This agreement refers to the Otis AFB Cooperative Conservation Plan dated 14 December 1962. Those plans are to be updated this fiscal year. The Massachusetts Division of Fisheries and Wildlife also maintains an active advisory program on natural resource and wildlife management issues with the Massachusetts Military Reservation Commission, currently the manager of most of the base.

The 60-acre PAVE PAWS site is located in the northwestern sector of Otis AFB Wildlife Management Area. The natural habitats at the site provide only marginal forage for deer because they are covered with dense growth of pitch pine and scrub oak. Nonetheless, the area in the general vicinity of Flat Rock Road is considered one of the better deer hunting areas of the Cape's resident deer. Hunting success in this area is evidently largely attributable to the ease of access for hunters and the presence of clearings created by power line and military maneuvers. In addition, the poor but suitable deer habitat is evidently offset by the relatively large contiguous land mass the deer can occupy.

Although the PAVE PAWS site itself is probably a poor nutritional source for deer, the unbroken woodlands provide escape, cover, and nesting areas for a wide variety of birds, including several species of game birds such as ruffed grouse and bobwhite quail. The Cape has approximately 100 bird species which breed there, as well as a very heavy concentration of migratory birds. The Cape, a major route of the Atlantic Flyway, has spring and fall migrations which involve about 100 and 200 species, respectively, with very large populations migrating through the area in the fall (Hill, 1965).

No federally-listed or state-listed endangered or threatened fauna have been reported from this area of the Cape (U.S. Fish and Wildlife Service, 1977; McCord, 1978). There is a slight possibility that the Plymouth red-bellied turtle (Chrysens rabiventris bangsi), a species proposed as an addition to the federal list of endangered species, might occur in ponds near Otis AFB (see Federal Register, May 19, 1978, Vol. 73, No. 98:21702-21705); however, no permanent aquatic habitat is present at the PAVE PAWS site itself. The proposed critical habitat of this turtle is in adjacent Plymouth County (Moser, 1978; McCord, 1978). The Plymouth red-bellied turtle is currently considered endangered by the Commonwealth of Massachusetts (Mass. Div. of Fisheries and Wildlife, 1978).

1.2.1.1.2 Electromagnetic Environment. The electromagnetic environment in the Cape Cod area can be described by discussing the electromagnetic spectrum there. The electromagnetic spectrum in the Cape Cod area is a renewable resource having the dimensions of amplitude, time, frequency, and space. It can be used continuously. In areas large enough to permit geographical separation, the spectrum will accommodate a number of users on the same frequency. In areas as small as Cape Cod, the spectrum will accommodate a large number of users only if they are separated in frequency. A high-amplitude signal can override a low-amplitude signal on the same frequency. The electromagnetic environment at a particular time comprises all the electromagnetic fields that are arriving there from numerous sources, both manmade and natural.

Some of the manmade contributions to the electromagnetic environment in the Cape Cod area are intentional, but others are accidental, and are incidental to some other activity. Radio signals of all sorts are intentional manmade contributions. The electromagnetic environment in the Cape Cod area consists in part of signals from various radio and TV stations at least as far away as Boston and Providence, from the radios of local law enforcement and fire departments, from local or transient CB operators, from the air navigation aides near the Hyannis airport, from passing aircraft, and so on. Because some signals can be reflected back to earth by high-altitude ionospheric layers, part of the electromagnetic environment in the Cape Cod area consists of transmissions from stations thousands of miles away.

The unintentional manmade contributions to the electromagnetic environment on Cape Cod are called manmade electromagnetic noise. Such noise is radiated by power lines, fluorescent lights, household lighting dimmer switches, household appliance motors, computers, hand-held calculators, and so on. A major contributor in the towns and along major roads such as the Mid-Cape Highway is the automobile ignition system, which radiates a pulse of energy over all the communication bands with each spark-plug firing.

Nature contributes noise to Cape Cod's electromagnetic environment. Lightning strokes in storm centers in Africa and South American cause "static" in Cape Cod radios, thousands of miles away. This noise is an intermittent major feature of part of the Cape's electromagnetic spectrum. In some parts of the electromagnetic spectrum, noise from the sun and from the stars (galactic noise) is often the predominant feature of Cape Cod's electromagnetic environment.

Overall, however, the Cape Cod area is a relatively low power density area. Ambient field measurements indicate that all other sources are far weaker than the PAVE PAWS radar (see Section B.2, p. B-1).

Human beings are not generally capable of sensing the electromagnetic environment or changes in it. Only radio receivers can do this. They sample portions of the spectrum to extract a small amount of energy, which they then amplify and convert to a usable signal. This signal might be in the form of a WJAR-TV picture, music from WCOD, a long-distance phone conversation, an airline navigation signal, or many others.

### 1.2.1.1.3 Soil, Water, Air, and Noise

1.2.1.1.3.1 Soil. Flatrock Hill, the project site, is located in an irregular, hilly, moderately-sloping upland ranging from 50 to 300 ft in elevation in the Seaboard Lowland section of the New England physiographic province. Flatrock Hill, with an elevation of 270 feet, is one of the highest points in the area. The western portion of Otis AFB lies on the Buzzards Bay Moraine (Strahler, 1972) -- an unstratified deposit of boulders, silt, sand, and gravel formed approximately 15,000 years ago (U.S. Geological Survey, 1976) during the waning stages of the last glaciation, the Wisconsin Stage of the Pleistocene Epoch. Boulders measuring more than 10 feet in diameter in the vicinity of Flatrock Hill are common. The variety of material deposited by the retreating glacier (including melting ice blocks) led to differential settling over time and produced the irregular landscape of hummocks and depressions now present. Although a detailed soil survey of Otis AFB has never been done, the general soil associations for the area have been established. The entire moraine area is composed of Plymouth soils, which are deep, excessively

drained, sandy soils that are extremely stony or bouldery in places. Their aridity and steep slopes severely limit intensive land uses such as agriculture and residential development (Pilgrim Area Resource Conservation and Development Project, 1975).

1.2.1.1.3.2. Water. Cape Cod has a humid continental climate moderated by a marine influence that reduces temperature extremes, producing a somewhat milder winter and cooler summer. During the winter months, coastal storms are fairly frequent, but snow generally does not remain on the ground for long periods. The average monthly precipitation is between 3 to 4 in, except in June and July, when it is less than 3 in (Cape Cod Planning and Economic Development Commission, 1978). The amount of precipitation influences groundwater levels and surface water runoff.

Water resources are important to the economic livelihood of Cape Cod, and have been identified as an area of critical concern by the Cape Cod Planning and Economic Development Commission (CCP&EDC) (1978). The commission has identified Otis AFB as the location of a future major groundwater supply for the Cape (Daniels and Magnuson, 1978). Surface water drainage is poorly developed and characterized by ponds, wetlands, and a lack of defined stream channels. Groundwater, on the other hand, is present in substantial quantities and is the sole source of drinking water for the base. The water-table map for western Cape Cod indicates that the groundwater level at Otis AFB ranges from 10 to 240 feet below the land surface (LeBlanc and Guswa, 1977). Groundwater quality is generally excellent, as indicated in recent testing of the water supply wells on Otis AFB by the Massachusetts Department of Environmental Quality (April 1978). However, one water supply well has been closed since it became contaminated from a leaking jet fuel line in 1972 (Marr, 1978). Because groundwater systems may take decades to recover from such contamination, much of the water quality planning for the area has concentrated on maintaining present quality, according to the official Cape Cod plan that complies with Section 208 of the Federal Water Pollution Control Act of 1972 (Water Quality Management Plan/EIS for Cape Cod, 1978).

1.2.1.1.3.3 Air. Cape Cod is in the Metropolitan Providence Interstate Air Quality Control Region (AQCR) number 120. The Environmental Protection Agency (EPA) reports air quality in the Massachusetts portion of AQCR 120 as better than federal standards for total suspended particulates, sulfur dioxide, carbon monoxide, and nitrogen dioxide. All areas in Massachusetts are reported as worse than the standard for oxidants (Federal Register, 1978). Of the many air quality monitoring stations in the AQCR, the station at Falmouth, south of Otis AFB, is closest to PAVE PAWS. In 1975, the Falmouth station reported annual sulfur dioxide and nitrogen dioxide values at 12% and 20%, respectively, of the maximum allow-

able concentrations according to EPA standards. The highest particulate 24 hour concentration measured at Falmouth station in 1975 was 71 micrograms/$m^3$, which is well below the federal standard of 260 micrograms/$m^3$. The Falmouth station does not monitor carbon monoxide or oxidant concentrations (EPA, 1977). The absence of Cape Cod from the Massachusetts list of Air Quality Maintenance Areas indicates that both the state and the EPA expects Cape Cod to meet the National Ambient Air Quality Standards through the early 1980s (EPA, 1975).

Air pollutants on Cape Cod are generated mainly by automobiles and other means of transportation. During the summer, traffic moving on and off the Cape emits thousands of tons of carbon monoxide, hydrocarbons, and nitrogen dioxide (EPA, 1977). Few industrial sources of pollutants exist on the Cape, with the important exception of the Canal Electric Power Plant located north of Otis AFB at the mouth of the Cape Cod Canal.

1.2.1.1.3.4 <u>Noise</u>. At present, the major source of noise in the vicinity of Flatrock Hill is the Mid Cape Highway (Route 6). Artillery fire and air traffic from Otis also contribute to noise levels around Flatrock Hill.

1.2.1.1.4 <u>Minerals and Other Resources</u>. The only mineral resources mined on Cape Cod at present are sand and gravel (Pilgrim Area Resource Conservation and Development Project, 1975). A number of gravel pits are located in the southern portion of Otis AFB and in the townships of Bourne, Mashpee, Sandwich, and Falmouth.

The forest and wildlife resources of Otis have essentially no economic value apart from recreational use. The trees are too small for lumber, pulpwood markets are nonexistent, and other sources of firewood are abundant closer to major markets. However, Otis provides about 3,000 person-days of deer hunting per year during a "deer week," and helps maintain herds off the site, providing an additional hunting resource. The base also has potential value as a grouse hunting area, containing perhaps the highest grouse population on the Cape (Hambly, 1978).

1.2.1.1.5 <u>Natural Disasters</u>. The Cape is subject to a variety of natural disasters. Storms of hurricane strength (winds greater than 73 mph) occur about 6 or 7 times per century, and an exceptionally strong hurricane may occur once per century.

Earthquake hazards are hard to estimate for New England, because of the rarity of severe earthquakes there (Ward, 1978) A recent National Science Foundation-National Bureau of Standards (1978) assessment of the risk gave the region an index value of 2

on a linear scale from 1 to 4. Hence, the risk is moderately stronger than most of the eastern half of the nation, but less than the risks west of the Rockies.

Tornadoes occur in Massachusetts about once per year (0.8 as frequent as the national average). They are generally small, however, and cause little damage (Lantzenheiser, 1969). Hail, icestorms, and wildfires represent the remaining hazards, but are infrequent.

### 1.2.1.2 Socioeconomic Characteristics

#### 1.2.1.2.1 Land Use and Aesthetics

1.2.1.2.1.1 Land Use. The Otis AFB military reservation contains 20,204 acres of land, most of which is owned by the Commonwealth of Massachusetts (see Table 1-1, p. 1-17). The Army leases a total of 14,705 acres, known as Camp Edwards, from the Commonwealth, including the 3,000-acre Otis AFB Wildlife Management Area. The wildlife area is maintained by the Massachusetts Division of Fish and Game, although it is also used by the Army National Guard as an artillery firing range. The Air Force leases about 2,210 acres and uses 1,132 government-owned acres. The Coast Guard leases 1,407 acres; in addition, the Veterans Administration has a government-owned 750-acre cemetery on Otis AFB (Creamer, 1978; Lustig, 1979). ++

The Otis AFB Wildlife Management Area is in the northern portion of the base and is separated from the Shawme Crowell State Forest by Route 6. + A third wildlife area, the Crane Wildlife Management Area, is situated to the south of the base (see Figure 1-6). In general, these three areas incorporate forested and + rolling terrain, open space and glacial kettle ponds -- each provides habitat for many animals, the most important of which is the white-tailed deer.

Major land development has not taken place on Otis AFB, but several decades of military use there have resulted in the alteration of part of the area's landscape and in the clearing of forest cover from several thousand acres. Nevertheless, an estimated 90% of the total base area remains forested; the remaining 10% includes the developed section along with the airfield near the southern boundary of Otis. At present, there are a number of abandoned buildings in the central area of the base as a result of the curtailment of Air Force activities during 1973.

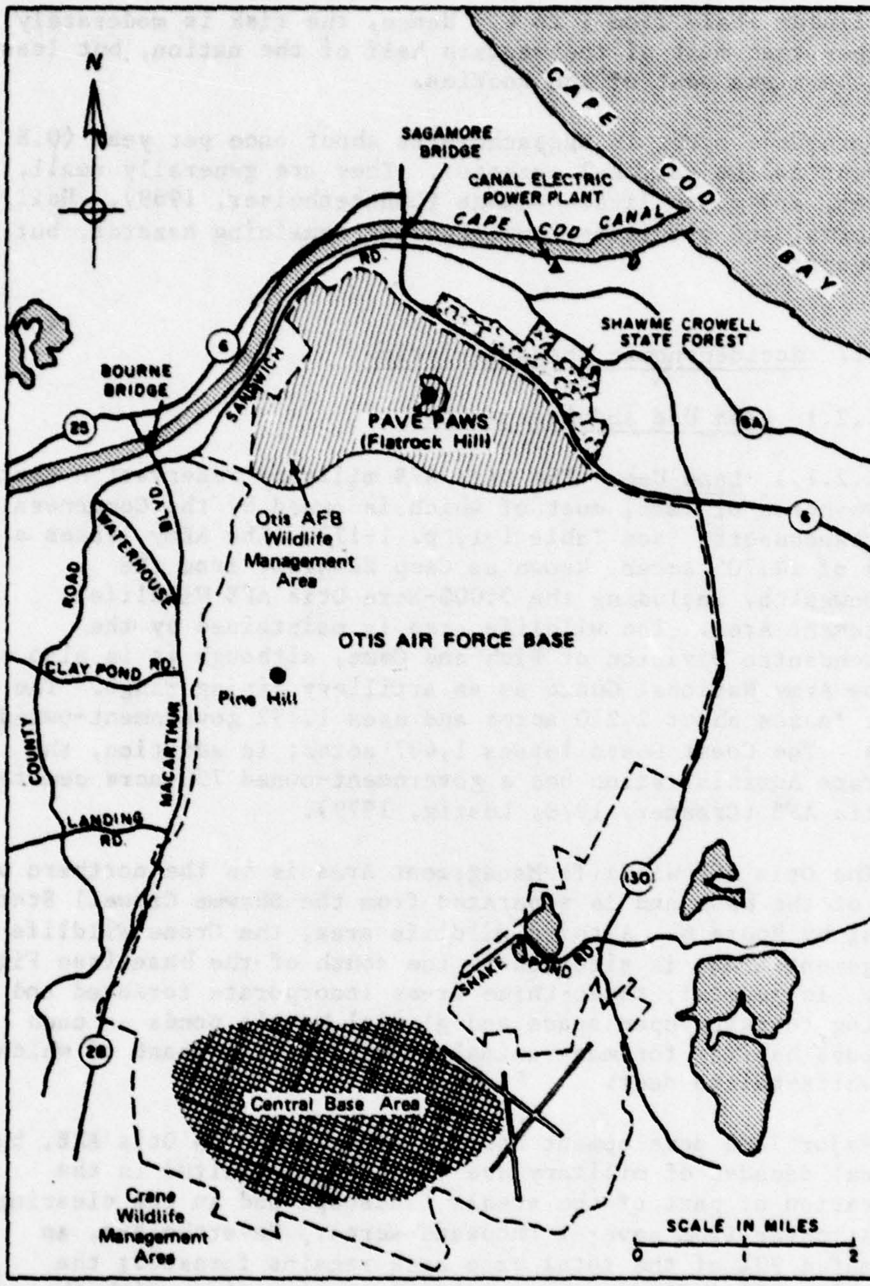



FIGURE 1-6. LAND USES AT OTIS AIR FORCE BASE

Table 1-1

LAND USE ON OTIS AIR FORCE BASE ++

| | Acres |
|---|---|
| U.S. Army (Camp Edwards) | 14,705 |
| U.S. Air Force | 3,342 |
| U.S. Coast Guard | 1,407 |
| Veterans Administration Cemetery | 750 |
| Total | 20,204 |

1.2.1.2.1.2 Aesthetics. Flatrock Hill and the area around it is characterized by thick forests and irregular terrain. Manmade structures visible in the area include water towers and transmission lines and towers. The most prominent manmade structure in the area is the Canal Electric Power Plant's 450-ft stack; it is located at the mouth of the Cape Cod Canal in the village of Sagamore, and is visible for many miles.

1.2.1.2.2 Demographics and Economics

1.2.1.2.2.1 Employment. Levels of employment have fluctuated greatly at Otis AFB throughout its history. The Air Force was the host in charge of the base until the early 1970s, when the Air Force phased out of Otis. Beginning in about 1972, the Coast Guard has been rapidly increasing its strength at Otis, and it is currently the largest single organization on-base. Many different organizations are currently stationed at the base: the Coast Guard, Army National Guard, Air National Guard, Marines, an Air Force maintenance crew, and a small number of other personnel (Coast Guard, 1978).

Table 1-2 shows the military and civilian personnel stationed at Otis AFB in 1977 and projections for 1979 without PAVE PAWS.

Table 1-2

EMPLOYMENT LEVELS AT OTIS AFB, 1977 AND PROJECTED 1979[a]

| | 1977 | | | 1979 |
|---|---|---|---|---|
| | Military | Civilian | Total | Total |
| Active-Duty Coast Guard | 445 | 665 | 1,110 | 1,170 |
| Army National Guard | 238 | 0 | 238 | 238 |
| Air National Guard | 69 | 0 | 69 | 69 |
| Marines | 23 | 0 | 23 | 28 |
| Army Command and Staff College | — | — | 0 | 325 |
| Total | 775 | 665 | 1,440 | 1,960 |

[a]Source: Coast Guard, 1978.

1.2.1.2.2.2 Population. About 500 personnel at Otis live on-base. Given an average family size of 3.5 (Coast Guard, 1978), about 1,750 people live on-base.

Officially, 2,668 personnel (1,472 active duty military, 1,196 civilians) were stationed at Otis AFB in 1977 (Stevenson, 1978). Many of those personnel, however, are at the base only on the weekends or for two weeks during the summer. The total number of personnel from all the various groups who work at Otis AFB year-round is approximately 600-700 people (Marr, 1978).

1.2.1.2.2.3 Income. The payroll for military and civilian personnel at Otis AFB has followed the path of employment at the base, steadily increasing from a low in 1973 of $9.9 million to a projected high in 1978 of $30.9 million (Coast Guard, 1978). Those figures do not include construction costs or personnel costs associated with PAVE PAWS.

1.2.1.2.2.4 Housing. There are a total of 1,193 housing units at Otis AFB. Only about half of them are livable, however; the remainder have been vacant since the Air Force left Otis, and are under the supervision of the base caretaker.

With the recent Coast Guard renovation of 110 housing units on-base, 559 units out of the 1,193 are livable. The addition of 42 units (soon to be available through Air Force financing) will raise that number to 601. All of the units are family quarters; there are no quarters for single military personnel on-base.

Housing on-base is available to any married active-duty personnel assigned to Otis. Each group on base has a quota of units available to that particular group; the Air Force, for example, will have 72 units for its personnel out of 601 livable units (Falcomidri, 1978).

Housing at Otis is in great demand because rents off-base are very high. About 500 of the 559 units are filled at any given time; there are always some vacancies because turnover is high. Demand for housing on-base has been increasing recently, and is expected to continue to grow (Falcomidri, 1978).

1.2.1.2.2.5 Education. The Bourne School District has three operating schools on-base at Otis: Stone and Otis Memorial elementary schools and Lyle Junior High School. A fourth school -- Clay Campbell -- has been closed since the early 1970s.

1.2.1.2.2.6 Health Care. There is a small medical clinic on Otis, with a staff of 1 physician, 13 hospital corpsmen, 1 physician's assistant, 1 dentist, and 2 dental technicians (all full-time). There is a position available for an additional physician (not connected with PAVE PAWS), which is yet to be filled. The clinic can take X-rays and dispense medicine, and handle medical problems such as colds and minor injuries (Rolsink, 1978).

Major medical problems are referred off-base to community facilities, such as Falmouth Hospital or one of the other local hospitals, or other military clinics, such as the naval hospital in Newport, Rhode Island, or the large clinic at Hanscom AFB in Bedford, Massachusetts.

### 1.2.2 Fort Fisher AFS, North Carolina

Operation of the PAVE PAWS radar facility would result in subsequent shutdown of Detachment 5, 14th Missile Warning Squadron, at Fort Fisher AFS, 18 miles south of Wilmington in New Hanover County, North Carolina. The small communities 1 and 4 mi north of the AFS -- Kure Beach, and Carolina Beach, respectively -- receive some economic benefit from the AFS, but depend mostly on revenue from tourism. Most of the local economic effects from Fort Fisher AFS are concentrated in Wilmington.

Fort Fisher AFS is maintained by the 701st Radar Squadron, which will continue to operate after Detachment 5 has left. The 701st Squadron will not be discontinued with the implementation of the Joint Surveillance System by the Federal Aviation Administration (FAA). At present, the commissary at Fort Fisher AFS does an annual business of $642,000 (fiscal year 1978), the base exchange (BX) an annual business of $235,100 (February 1977-January 1978), and the non-commissioned officers (NCO) Club has yearly sales of $65,000 (a two-year average, 1975-1977).

Fort Fisher AFS is a self-sufficient operation. It has two deep wells, which provide all of the base's water supply; it has six diesel generators, which are used as a back-up power system; it has a central heating plant that supplies both of the radar towers; and it has a package sewage-treatment plant to treat wastewater. Heating for all of the buildings is supplied from commercial sources except for the radar towers.

1.2.2.1 Biophysical Characteristics

Because the biophysical characteristics of the Fort Fisher AFS site will be relatively unaffected by the deactivation of Detachment 5, a detailed description of them is not provided.

1.2.2.2 Socioeconomic Characteristics

1.2.2.2.1 Land Use and Aesthetics. Fort Fisher AFS is located on U.S. Route 421 at the end of a peninsula that is a popular resort area. The AFS consists of 235 acres, of which about half is residential and half is the operations area.

1.2.2.2.2 Demographics and Economics

1.2.2.2.2.1 Employment. Detachment 5 employs a total of 54 persons, 52 military (8 officers and 44 enlisted men) and 2 civilian. Among the military personnel, two people are under 20 years old; fifteen are between 20 and 24; twelve are in the 25-to-30 range; fourteen are between 30 and 35, and nine people are over 35.

There are 129 personnel assigned to the 701st Radar Squadron, of whom 18 are civilians.

1.2.2.2.2.2 Population. Of the 54 people assigned to Detachment 5, 39 are married and 15 are single. The average family size of married military personnel is 3.5 and of married civilians, 3. Thus, the total population associated with Detachment 5 is about 190 people, counting military and civilian personnel and their dependents.

1.2.2.2.2.3 Income. Wages (1978) for officers, enlisted men, and civilians average $22,800, $10,200, and $18,600 respectively. Annual wages for Detachment 5 are, therefore, $668,400.

1.2.2.2.2.4 Expenditures. Total expenditures associated with the direct operation of both Detachment 5 and the 701st Radar Squadron are: $72,200 (utilities), $35,400 (fuel), and $1,100 (contract maintenance), for a total expenditure of $108,700 annually.

It is estimated that about $500,000 is spent annually in Wilmington and other local communities because of the presence of Detachment 5 (Hess, 1978). Included is spending on operation and maintenance projects, communications, and personal spending by military and civilian employees.

1.2.2.2.2.5 Housing. There are 27 houses and a trailer court at Fort Fisher AFS. The trailer court currently has about 10 trailers, and could accommodate a total of 23. There is always a waiting list of people who want to live in base housing; at present 13 are on the waiting list, and it has been as high as 26.

The breakdown of on-base and off-base housing units inhabited by Detachment 5 is as follows:

| On-Base | Off-Base |
|---|---|
| Family quarters - 11 | Owner-occupied - 9 |
| Bachelor quarters - 10 | Renter-occupied, single family - 16 |
| | Renter-occupied, multi-family - 8. |

1.2.2.2.2.6 Education. There are no schools on the AFS. All 42 of the military and civilian school-age children attend local schools; mostly in Wilmington.

1.2.2.2.2.7 Health Care. There is a small medical clinic on Fort Fisher AFS that is currently staffed by 1 physician (who comes to the base two times a week), 3 full-time medical technicians, and 1 full-time dentist.

Military personnel at Fort Fisher AFS also use the medical facilities at Myrtle Beach AFB and Camp LeJeune, and civilian hospitals in Wilmington.

### 1.2.3 Charleston AFS, Maine

Operation of the PAVE PAWS radar facility on Cape Cod would result in subsequent shutdown of Detachment 6, 14th Missile Warning Squadron at Charleston AFS in Maine. The station is 3 miles west of the village of Charleston in southwestern Penobscot County and is approximately halfway between the communities of East Corinth (Penobscot County) and Dover-Foxcroft (Piscataquis County). Bangor, which is the largest community in Penobscot County and is 30 miles southeast of Charleston AFS, is the site of various military support facilities associated with the station. Of the smaller communities nearer to the station, Dover-Foxcroft, the administrative center of Piscataquis County, is the most affected both socially and economically by Charleston AFS.

Charleston AFS is maintained by the 765th Radar Squadron. Detachment 6, 14th Missile Warning Squadron, a tenant unit at Charleston AFS, will be eliminated with the implementation of the PAVE PAWS system. With the elimination of this unit, the station will close entirely. At present, the site formerly known as Dow Air Force Base, outside Bangor at the International Airport, has military support facilities that still serve both Squadron and Detachment personnel at Charleston AFS. The commissary at Dow does an annual business of $3.6 million, the BX an annual business of $667,000 and the NCO Club Annex has yearly sales of $800,000.

Charleston AFS is self-sufficient in most respects: its water supply is derived from two wells located on site; four diesel generators supply most of the power required; the central heating plant supplies the operations buildings; and waste water is treated by a package sewage treatment plant. Charleston AFS's BX is housed in two small trailers and is used mostly by retired personnel -- sales are approximately $40,000 per year.

#### 1.2.3.1 Biophysical Characteristics

Because the biophysical characteristics of the Charleston site will be relatively unaffected by the deactivation of Detachment 6, a detailed description of them is not provided.

#### 1.2.3.2 Socioeconomic Characteristics

1.2.3.2.1 Land Use and Aesthetics. Charleston AFS is located off State Route 15, which connects Bangor, the major population center of Penobscot County, with Dover-Foxcroft, the administrative center of Piscataquis County. The station covers a 77-acre site on the outskirts of Charleston known as Bull Hill and has three major land-use areas:

- Operations area -- 54,000 sq ft (1.2 acres)

- o Cantonment (troop quarters) area -- 62,000 sq ft (1.4 acres)

- o Residential area -- 58,000 sq ft (1.3 acres).

Most of the land within the station has not been developed.

1.2.3.2.2 <u>Demographics and Economics</u>

1.2.3.2.2.1 <u>Employment</u>. Detachment 6 employs a total of 44 persons, 43 military men (8 officers and 35 enlisted men) and 1 civilian. One of these employees is under 20; fifteen are between 20 and 24; thirteen are between 25 and 29; ten are between 30 and 34; and five are 35 or older.

The 765th Radar Squadron employs 169 military personnel. The Squadron provides 23 appropriated and 7 nonappropriated civilian positions, not including the 43 military personnel and 1 civilian employed by the Detachment.

Seventy-five civilian personnel are employed at the military support facilities at Dow AFB outside Bangor.

1.2.3.2.2.2 <u>Population</u>. Of the 44 employed by the Detachment, 10 persons are single and 34 are married. The average family size for married military personnel is 3.4, and the civilian family has 4 persons. Therefore, the total population associated with the Detachment at Charleston AFS is about 126. There are 38 school age children.

1.2.3.2.2.3 <u>Income</u>. Average wages (1978) for officers, enlisted men and civilians are $22,800, $10,200, and $18,600, respectively. Thus, annual earnings directly associated with the Detachment are approximately $568,000.

1.2.3.2.2.4 <u>Expenditures</u>. Expenditures associated with direct operation of the radar facility at Charleston are $68,800 for utilities, $153,900 for fuel, and $800 for contract maintenance. The total for these three categories is $223,500.

It is estimated that 95% of the station personnel's off-base expenditures are made in Penobscot County; approximately 90% are made in the Bangor City area and the remaining 5% in Dover-Foxcroft (<u>Environmental Assessment, JSS, 765 RADS</u>, 1978).

1.2.3.2.2.5 <u>Housing</u>. Charleston AFS has 37 family housing units. Most of these are occupied by 765th Radar Squadron personnel. The number and location of on-base and off-base housing units inhabited by Detachment 6 personnel are:

o On-Base

- Family quarters -- 31 (3 at Charleston and 28 at former Dow Air Force Base site outside Bangor)

- Bachelor quarters -- 8 (all at Charleston AFS).

o *Off-Base*

- Owner-occupied -- 4
- Renter occupied, multifamily -- 1.

Dow AFB has 165 moderate income military housing units, 80 of which are occupied by Charleston AFS personnel; 56 of the housing units are occupied by other armed forces personnel and 29 are vacant.

1.2.3.2.2.6 Education. There are no schools at Charleston AFS. All of the 138 Air Force children and 12 civilian employees' children attend the local schools.

Thirty-four of the school age children associated with Detachment 6 attend school in Bangor. (Some travel on a commuting bus that runs on a regular basis between Bangor and Charleston.) The other four go to elementary schools in School District 68; two go to school in the town of Charleston and two in Dover-Foxcroft. No high school students from the station attend the high school in Dover-Foxcroft.

1.2.3.2.2.7 Health Care. Records of approximately 2,100 retired military personnel are maintained at the Charleston Station Medical Facility, which is manned by 2 medics. The Air Force contracts for a doctor to visit the facility three times a week. The nearest Department of Defense medical facility is at Brunswick Naval Air Station, approximately 100 miles south. However, personnel at Charleston are required to use the facilities at Pease Air Force Base, even though it is approximately 200 miles away, for scheduled surgery and other medical needs.

## Chapter 2

## RELATIONSHIP OF THE PROPOSED ACTION TO LAND USE PLANS, POLICIES, AND CONTROLS FOR THE AFFECTED AREA

Otis AFB incorporates land within the town limits of Bourne, Sandwich, Mashpee, and Falmouth, the region known as the Upper Cape (see Figure 2-1). Land areas of these towns outside the Base, in addition to those within, could potentially be affected by the proposed action. Therefore, the land use plans, policies, and controls that are applicable to those four towns, as well as to Cape Cod and the state as a whole, are relevant to this analysis.

### 2.1 The Affected Area

All four towns surrounding Otis AFB are within Barnstable County, which incorporates a relatively small section of land between the border with Plymouth County and the Cape Cod Canal, as well as the entire Cape Cod peninsula stretching from the Canal to Provincetown. Of the 253,000 acres on Cape Cod, 64,000 acres (25%) had been developed for residential and commercial uses as of 1975. Another 52,000 acres (21%) are expected to be developed over the next 20 years.

Cape Cod is the second fastest-growing region in Massachusetts in percentage terms. A nearly 40% increase in the year-round population has occurred since 1970 -- 6,000 new residents have moved to the Cape each year. (Population totaled 130,000 during the winter of 1975-76 and was as high as 380,000 during the summer months that year.) The local response to this rate of growth has been mixed; some have benefitted from employment opportunities and the higher tax base. However, others feel that the future of the economy will be dependent on the preservation of the natural environment and local character of the Cape, both of which they feel are being damaged by such fast growth. Furthermore, additional second home and seasonal communities will continue to force local governments to provide public services that are not utilized efficiently year-round.

In the mid-1970s, Bourne suffered an abnormal fluctuation in population when most Air Force operations were discontinued at Otis in 1973. The high population growth rate (5% annual average) of the two decades between 1950 and 1970 declined. However,

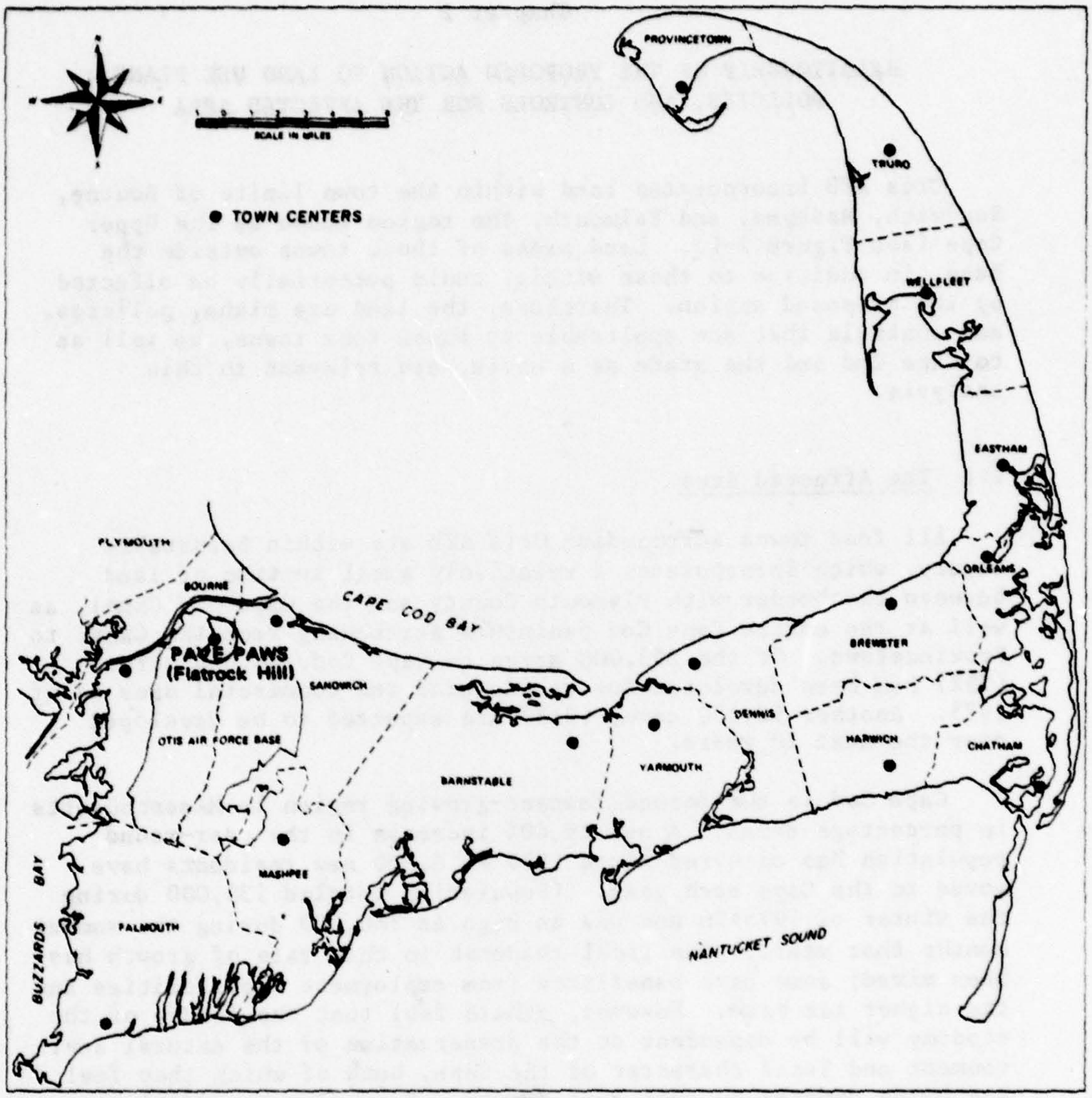



FIGURE 2-1. THE LOCATION OF THE PROPOSED ACTION

recreationalists, second-home builders, and families moving out of such high-density urban areas as Boston are imposing new pressures on Bourne's undeveloped land area. In 1971, Bourne had an average of 289 people per square mile and the largest percentage of forested land and open space in Barnstable County. By 1975, despite the partial closing of Otis, 4,800 or 18% of the town's 26,000 acres had been developed, while 7,800 (30%) were considered developable and 9,600 (37%) were designated reserved for open space (Water Quality Management Plan/EIS for Cape Cod, 1978).

Sandwich's population shifts may also be attributable to operational changes at Otis. Between 1950 and 1970, population increased by 118% and the physical character of the town changed as well. In 1971, there were approximately 118 people per square mile within Sandwich's 27,700 acres. Data from 1975 indicate that 20% of the town's total acreage had been developed, 34% was buildable, and 35% had been set aside as open space.

Mashpee's population grew by 194% between 1950 and 1970 with related urbanization and loss of open space. In 1971, the population density of Mashpee was only 49 persons per square mile. Of 14,600 acres, 2,500 acres (17%) were developed in 1975, 8,500 acres (58%) were considered developable, and 1,100 acres were reserved for recreation and other related uses.

Falmouth is the most densely populated of the towns surrounding Otis with 324 people for each square mile. In the 20 years between 1950 and 1970, urban expansion consumed acres of farmland, pastureland, and forest, although the 84% increase in population was low relative to the county. By 197[illegible] of 28,300 acres in the town, 8,400 acres (30%) had been developed, 14,900 acres (53%) were still buildable, and only 800 acres (3%) were designated as preserved.

## 2.2 Land Use Plans

Several plans have been proposed for land use within and on the periphery of Otis Air Force Base. These plans include:

- o The Coast Guard Unit Development Plan
- o The Otis Park Concept Plan
- o The alteration of Routes 25 and 28.

### 2.2.1 Coast Guard Unit Development Plan

The Coast Guard will be formulating a plan in 1979 to modify the air station facilities at Otis to be better equipped to handle new aircraft that will be landing there. The plan, according to

information provided by officials ("Fact Sheet on U.S. Coast Guard at Otis/Camp Edwards," 1978), is expected to entail removal and replacement of existing operations and administration facilities as well as construction of additional hangar facilities, of an exchange/grocery/shop complex and of a supply warehouse. There does not appear to be any conflict in land use between the Coast Guard's plan for facility expansion and the Air Force's plan for PAVE PAWS. The Air Station complex is in the southern portion of Otis while the site for PAVE PAWS is in the northern section (see Figure 2-2).

### 2.2.2 Otis Park

In 1973, several portions of Otis AFB which had been leased by the Federal government were returned to the Commonwealth of Massachusetts. Consequently, an Otis Task Force was formed by the Joint Commission on Federal Base Conversion with funding provided by the New England Regional Commission and directed through the Governor's Office to consider options for use of a 3,000-acre parcel in the southern quarter of the base (see Figure 2-2). The Task Force has commissioned a number of studies addressing reuse of this land, including:

- The Potential Use of Otis AFB for Recreation
- Housing Conversion Analysis for Otis AFB
- Otis AFB Visitor/Craft Center Feasibility Study.

The objectives stated in the fourth and latest report (Otis Park Concept Plan, 1976), which encompasses several proposals from the earlier studies, are to encourage increased economic activity by attracting visitors (a minimum of 28 full-time and 64 part-time primary jobs could be created); to conserve undeveloped lands; and to set aside potentially developable land and enhance its attractiveness through land management practices. The specific elements of the reuse plan are:

- Craft village and visitor center
- Campgrounds
- National veterans cemetery
- Veterinary medical college
- Civilian housing
- Golf course
- Horse riding facilities

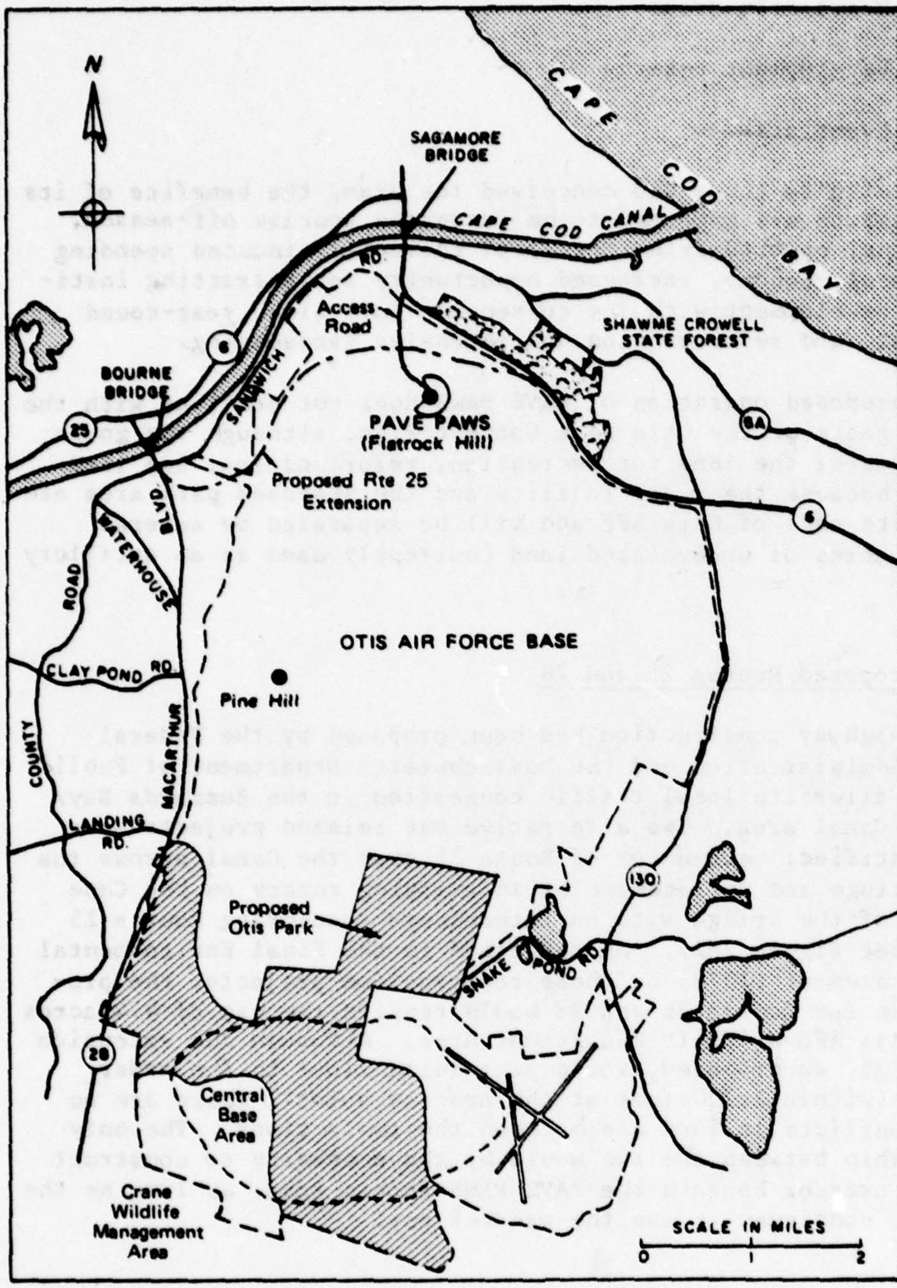



FIGURE 2-2. PROPOSED LAND USE PLANS AFFECTING OTIS AIR FORCE BASE

- Recreation areas
- Development reserve
- Event area.

According to those who conceived the plan, the benefits of its implementation are expected to be increased tourism off-season, recreational opportunities for local residents, induced spending in the local economy, increased opportunity for attracting institutional development with its consequent full-time, year-round employment, and reforestation and intensive landscaping.

The proposed operation of PAVE PAWS does not conflict with the land use goals of the Otis Park Concept Plan, although the goals specify use of the land for recreation, reforestation, and landscaping, because the radar facility and the proposed park area are at opposite ends of Otis AFB and will be separated by several thousand acres of undeveloped land (currently used as an artillery range).

### 2.2.3 Proposed Routes 25 and 28

New highway construction has been proposed by the Federal Highway Administration and the Massachusetts Department of Public Works to alleviate local traffic congestion in the Buzzards Bay/Cape Cod Canal area. Two alternative but related projects have been identified: extension of Route 25 over the Canal across the Bourne Bridge and replacement of an existing rotary on the Cape Cod side of the bridge with an interchange connecting Routes 25 and 28 (see Figure 2-2). As described in the Final Environmental Impact Statement (1978) on these construction projects, the proposed plan for Routes 25 and 28 would require the use of 4.4 acres in the Otis AFB Wildlife Management Area. Although the extension of Route 25, as proposed, would pass quite close to the radar facility (within 2,700 feet at the nearest point), there are no direct conflicts in land use between the two actions. The only relationship between the two would be the necessity to construct Route 25 over or beneath the PAVE PAWS access road, as long as the Air Force continues to use the present one.

## 2.3 Land Use Policies

In the past, growth on Cape Cod was largely unrestricted by zoning and primarily took place near the shore and in coastal village and town centers. Development inland was minimal until the last 10 to 15 years when interior areas became the focus of growth-related activity. Now the principal land use policy being communicated at the state level in Massachusetts is that growth should be diverted from outlying, low density rural and sprawl

areas to regional and community centers. The rationale behind this policy, as stated in a recent report of the Massachusetts Office of State Planning, (City and Town Centers: A Program for Growth, 1977), is that "efficiency and environmental protection would be better served by growth being more spatially concentrated than it has been." The 208 plan (Water Quality Management Plan/EIS for Cape Cod, 1978) recommends that growth be focused in four regional centers and ten community centers on the Cape. Currently, efforts are being made to improve the village centers of Falmouth, Woods Hole, Hyannis, Barnstable, Chatham, and Provincetown.

During 1976, Local Growth Policy Committees were formed in each Cape Cod town in compliance with the Massachusetts Growth Policy Development Act passed in 1975. These statements were incorporated into City and Town Centers: A Program for Growth by the Office of State Planning and the Cape Cod Planning and Economic Development Commission. In the Local Growth Policy Statements prepared for many of the individual towns, the pervading theme is that better management of the rate of growth would allow more careful planning and thus mitigation of any negative consequences. The town of Bourne has adopted a bylaw concerning growth management that may very likely serve as a model for other Cape towns. The bylaw regulates the number of residential construction permits that can be issued in a specifed time period.

The Cape Cod Growth Policy Report summarizes the land use concerns of some local towns: "As more open space is consumed with widespread residential development, and as strip commercial development envelopes once-scenic roadways, the Cape's fragile landscape is irrevocably scarred. In fact, the effects of the Cape's tourist-related economy threaten the very attractions that sustain the industry."

The PAVE PAWS facility has been constructed partially within the Otis AFB Wildlife Management Area requiring 60 acres of previously open space. That land will be withdrawn from other uses for at least the operating lifetime of the facility. Thus, the land will not be available for use by resident wildlife or by local hunters who had been, until the time of construction, permitted in the area during certain times of the year. Use of the 60 acres for recreational purposes will be prohibited.

The type of development that PAVE PAWS itself represents is neither in concert nor in conflict with growth-related policy in the area. Presumably, the 200 personnel associated with the radar will either live in existing on-base housing or will rent or purchase housing facilities in already developed areas (probably the town centers of Sandwich, Bourne, Falmouth, and Mashpee). Few are expected to construct their own homes; therefore, PAVE PAWS is not likely to foster the kind of unexpected peripheral development

that is contrary to the land use policies of the Cape and its towns.

## 2.4 Land Use Controls

The land being used by the military at Otis is owned by the Commonwealth of Massachusetts and thus is not subject to local or regional regulations.

If any development activity takes place on privately-owned land outside the base as an indirect result of the proposed action, compliance with state, regional, and local land use controls will be required. Controls at the state level are:

- Massachusetts Wetland Protection Laws.
- Growth Policy Development Act (Chapter 807 of the Acts of 1975).
- Massachusetts Coastal Zone Management Program (all 15 towns on the Cape are within the Coastal Zone).
- Massachusetts 208 Wastewater Management Plan.

Local and regional regulations include:

- Local zoning regulations enforced by local planning boards
- Bourne Growth Management Bylaw.

Various regulatory agencies enforce these laws. Implementing agencies at the state level include:

- Executive Office of Environmental Affairs
- Department of Community Affairs
- Office of State Planning
- Department of Public Works
- Executive Office of Transportation and Construction.

Regulatory groups at the local and regional level are:

- Planning boards
- Cape Cod Planning and Economic Development Commission
- Old King's Highway Regional Historic District Commission.

## Chapter 3

## PROBABLE IMPACT OF THE PROPOSED ACTION ON THE ENVIRONMENT

### 3.1 Otis AFB, Massachusetts

#### 3.1.1 Exposure to Electromagnetic Radiation (EMR)

Because the proposed action is the operation of the PAVE PAWS radar, the direct impacts on the environment center on the magnitude, nature, and distribution of the EMR. A comprehensive technical description of the EMR is given in Appendix A, and a comparison of calculated values with measurements at specified locations is presented in Appendix B. Special features of the EMR that pertain to electromagnetic interference are further described in Appendix D. Calculated values in this section are based on the field model described in Section A.3, p. A-9. Comparison of the measured and calculated values permits the conclusion that the field model is well founded and conservative (see Tables B-4 and B-5, pp. B-11 and B-13).

This section describes the power density of the basic system EMR in the immediate vicinity of PAVE PAWS at and near ground level (below 300 ft above mean sea level), which the main beam of the radar is constrained from illuminating. (The growth system EMR is described in Section 3.1.4, p. 3-93.) However, the first- and higher-order sidelobes will contribute to the power density of the EMR near ground level. Because the power density increases as the antenna face is approached, the highest densities that can be encountered without entering the posted exclusion fence area are found just outside the exclusion fence (see Figure 1-3, p. 1-4), well within the boundaries of a military reservation.

The following description (and Section 3.1.4, p. 3-93, for the growth system) provides a context for the later sections that describe effects that have been attributed to EMR similar to that of PAVE PAWS. For that purpose, in this section time averages of the EMR are used in all tables and figures, and an 18% duty cycle (the maximum percentage of time radiating for simultaneous operation of both faces) is assumed. However, some specific effects related to electromagnetic interference depend on the pulse power density and other technical specifications of the individual pulses. Appendix D must be consulted for a technical description of the EMR related to those effects. Appendix A also exhibits pulse power densities. +

### 3.1.1.1 General Description of EMR Power Density from PAVE PAWS

#### 3.1.1.1.1 Power Density at Distances Greater than 1,000 Ft.

Figure 3-1 shows the immediate vicinity of the PAVE PAWS radar at Otis AFB. The radial lines mark the boundaries of sectors in which the EMR power density will be described. The sectors differ in power density because of the geometry describing the radar coverage of each face. The first sidelobe, following the main beam, sweeps through 120 degrees in azimuth centered on each face (240 deg in azimuth overall), but the higher-order sidelobes, taken together, fill the hemisphere in front of each face with EMR. These hemispheres overlap in Sector 1 of Figure 3-1. Consequently, EMR is highest in that sector. In Sector 3, the first sidelobe does not contribute to the power density at any altitude. Hence, EMR is lowest generally in that sector. Finally, in Sector 2, EMR power density is generally intermediate in value compared with the density in the adjoining sectors. Each sector shown is keyed to figures that describe EMR power density in relation to distance from PAVE PAWS and to elevation above mean sea level (MSL). The partial circles shown in Figure 3-1 denote distance from the radar.

Figures 3-2 through 3-8, pp. 3-4 through 3-10, describe the calculated EMR power density from the basic PAVE PAWS system. The EMR power densities shown in all figures assume no attenuation from vegetation or from intervening terrain, and are based on calculated rather than measured values (see Appendix B for the comparison, which shows, within respective uncertainties, that the measured values were less than or equal to calculated values). Power densities actually experienced at any location could be smaller than those illustrated by a factor of up to about 10 because of intervening vegetation, and by a similar factor because of intervening terrain (i.e., a combined factor of up to 100). Power densities could also be slightly higher over some limited regions (hot spots), because of reinforcing reflections, but actual field measurements to date have indicated power densities equal to or less than calculated values.

Figure 3-2 describes the part of the transition region at ground level from the exclusion fence distance, 1,000 ft, out to the beginning of the far field region, around 1,500 ft from the face. Figures 3-3 through 3-8 describe EMR power density from 1,500 ft to 25,000 ft from the radar, and from 0 to 300 ft MSL in elevation. The figures are keyed to the sectors defined in Figure 3-1. Power density varies with elevation because of the proximity to the first sidelobe. At higher elevations, exposure to the first sidelobe may occur for three to four adjacent pulse intervals as the main beam makes a sweep over 120 deg in azimuth at 2-deg intervals (see Appendix A for details of the geometry). This circumstance increases exposure from the first sidelobe to a maximum factor of about 2.5 times larger than the maximum exposure from one pulse.

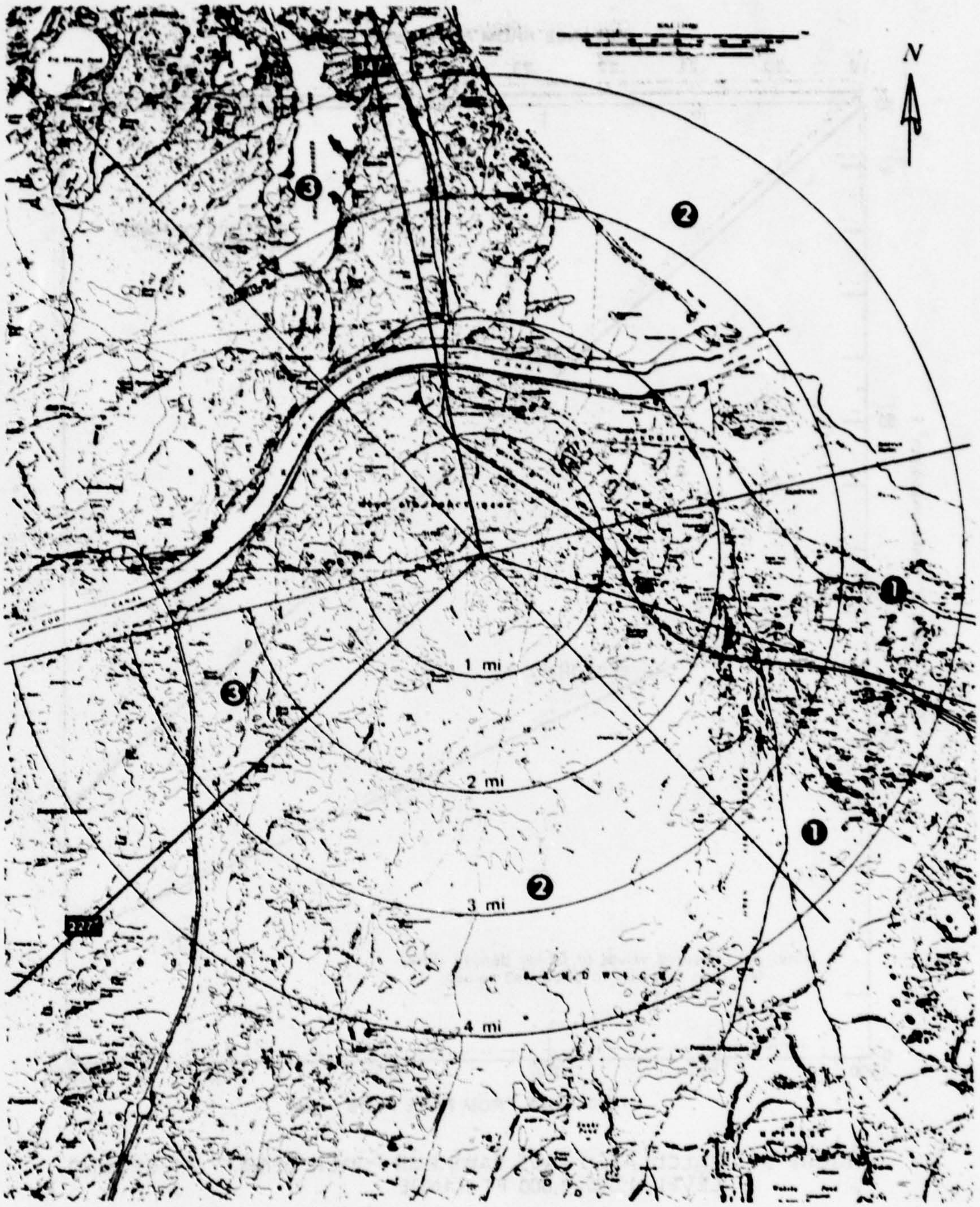



FIGURE 3-1. PAVE PAWS AZIMUTH FROM FLATROCK HILL

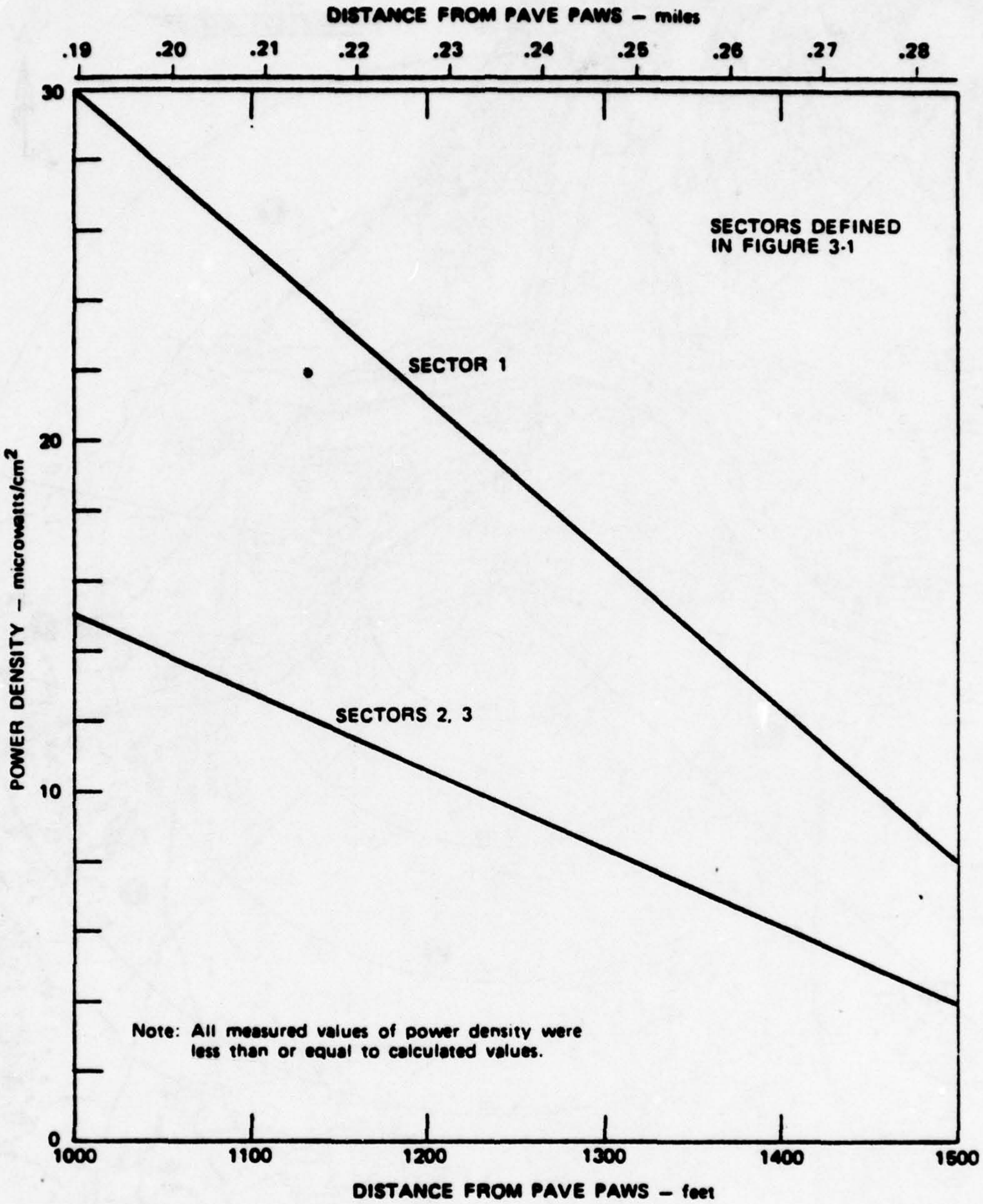



FIGURE 3-2. CALCULATED PAVE PAWS EMR POWER DENSITY AT GROUND LEVEL, 1,000–1,500 FT RANGE

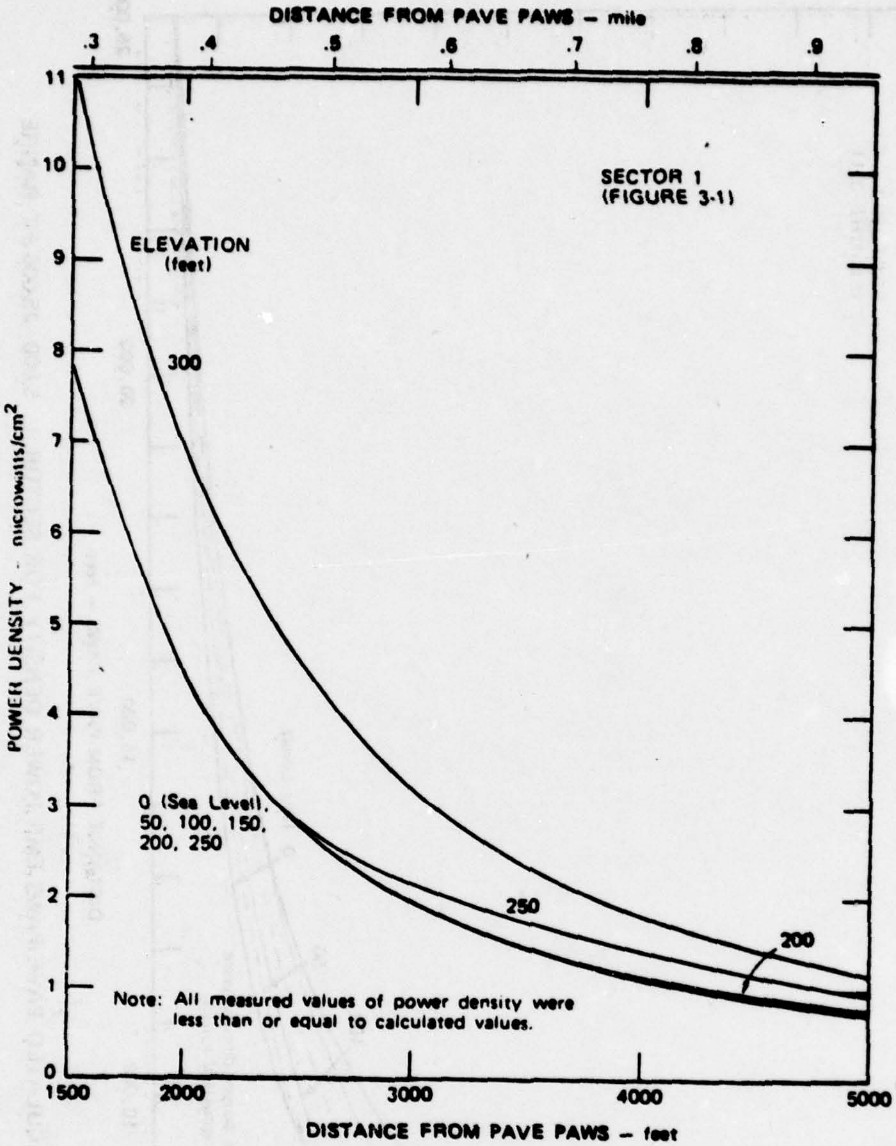



FIGURE 3-3. CALCULATED PAVE PAWS EMR POWER DENSITY FOR SECTOR 1, 1,500–5,000 FT RANGE

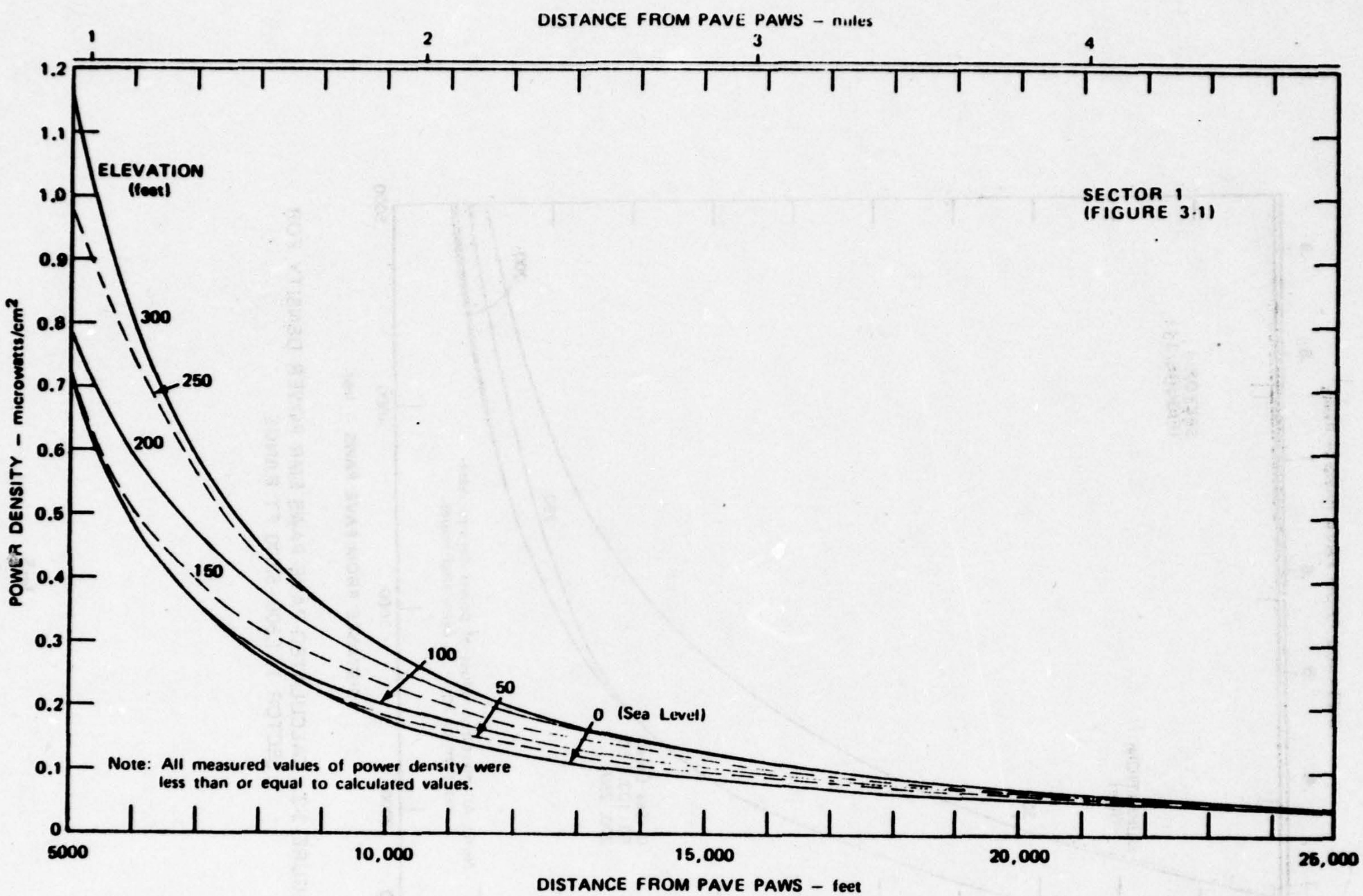



FIGURE 3-4. CALCULATED PAVE PAWS EMR POWER DENSITY FOR SECTOR 1, 5,000–25,000 FT RANGE

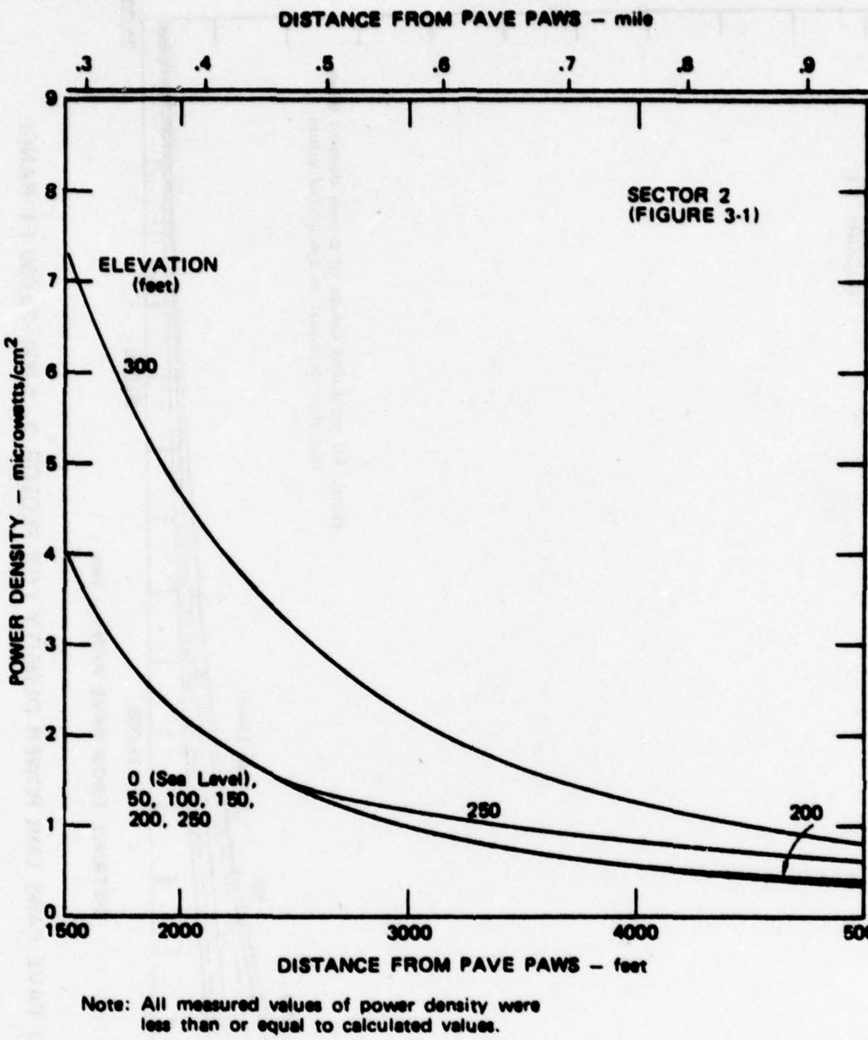



FIGURE 3-5. CALCULATED PAVE PAWS EMR POWER DENSITY FOR SECTOR 2, 1,500–5,000 FT RANGE

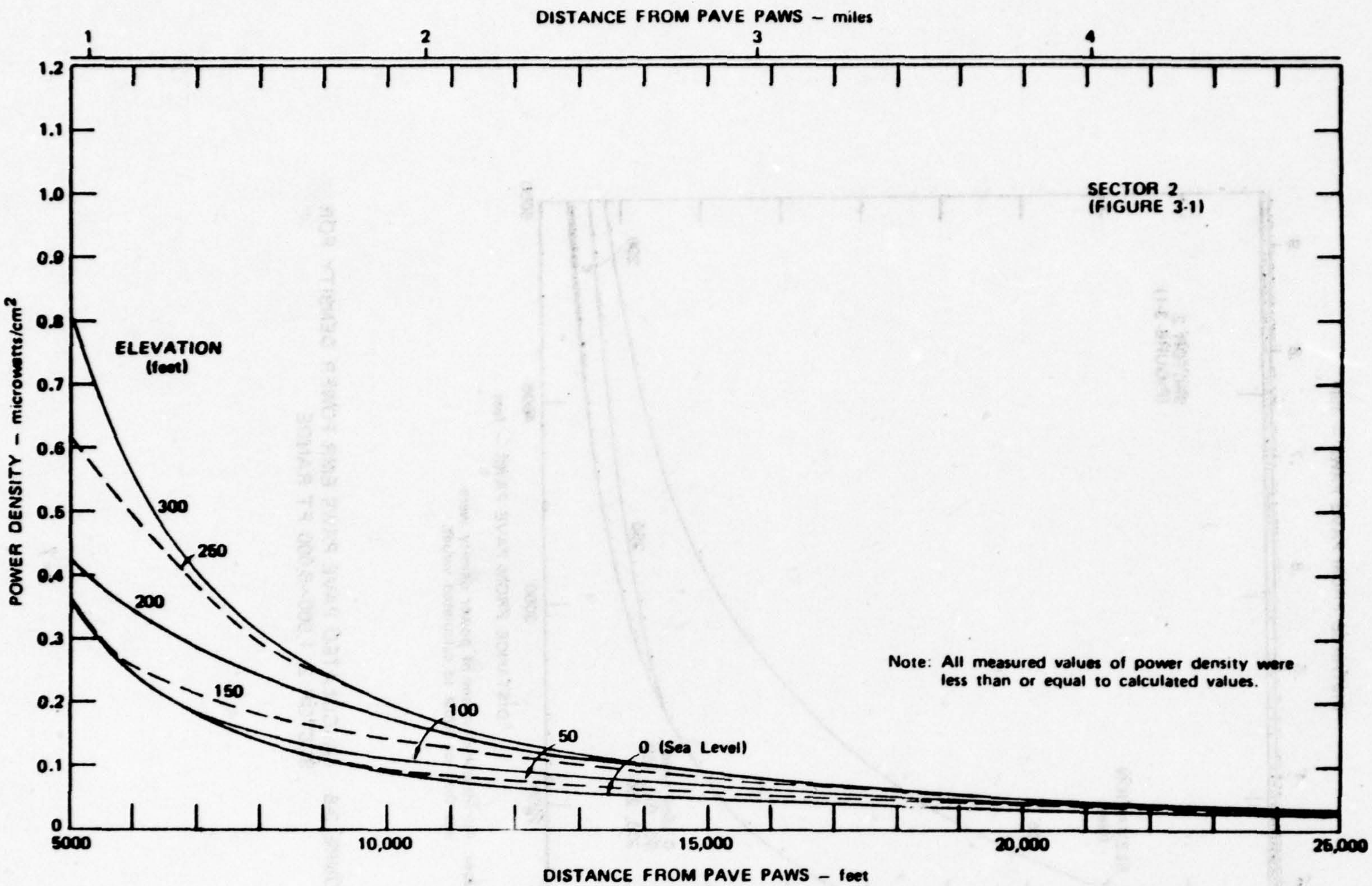



FIGURE 3-6. CALCULATED PAVE PAWS EMR POWER DENSITY FOR SECTOR 2, 5,000–25,000 FT RANGE

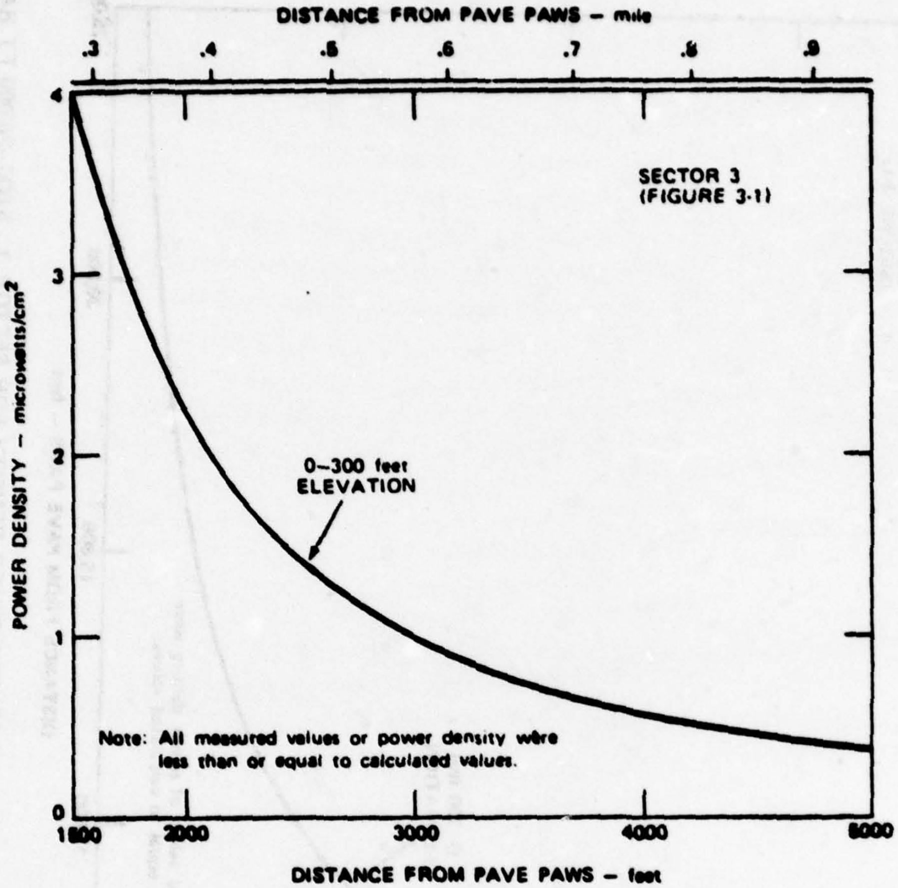



FIGURE 3-7. CALCULATED PAVE PAWS EMR POWER DENSITY FOR SECTOR 3, 1,500–5,000 FT RANGE

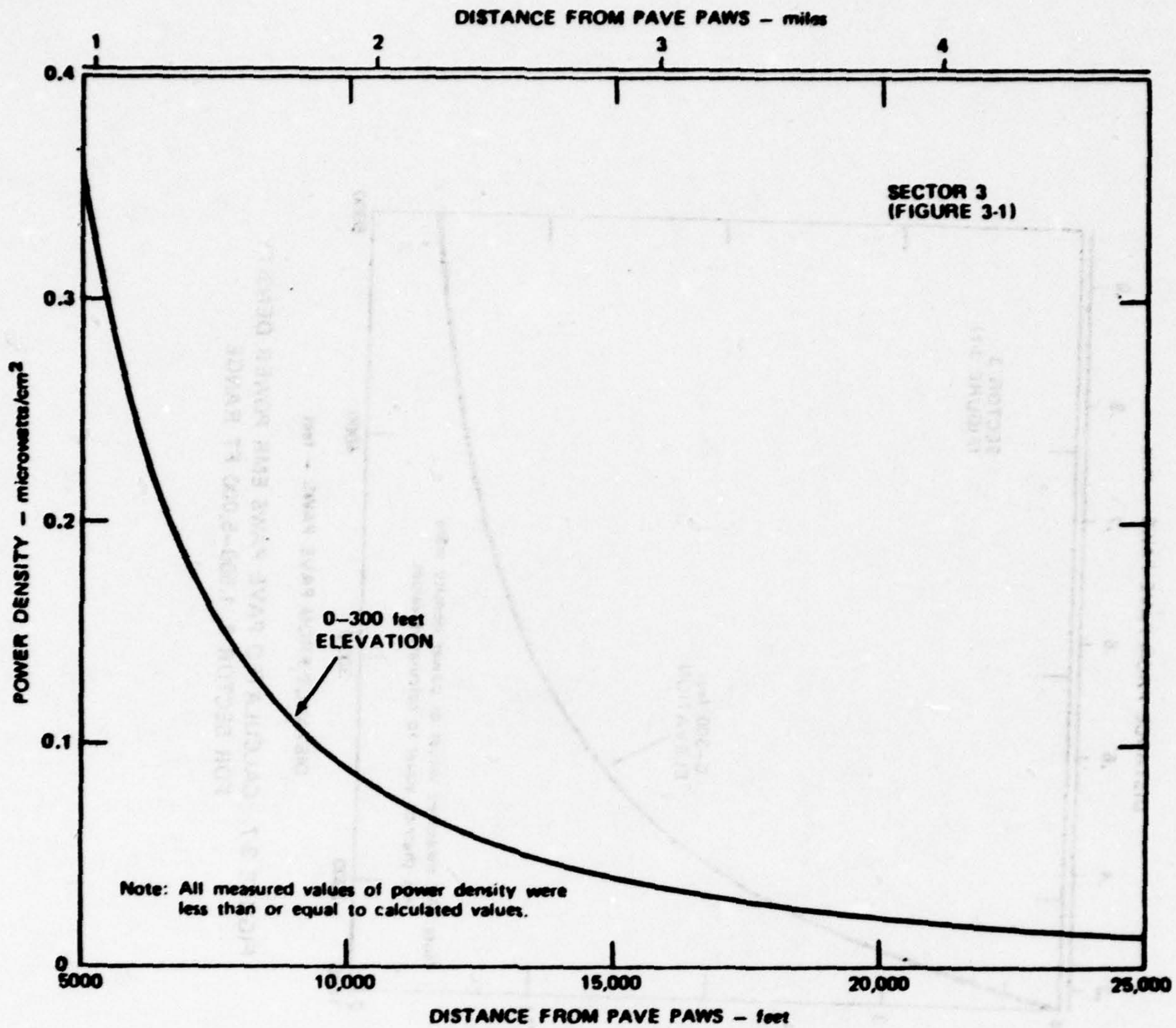



FIGURE 3-8. CALCULATED PAVE PAWS EMR POWER DENSITY FOR SECTOR 3, 5,000–25,000 FT RANGE

3.1.1.1.2 **Power Densities within 1,000 ft of the Antenna.** The exclusion fence is intended to prevent man and some animals from inadvertently approaching closer than about 1,000 ft from the antenna faces. However, the fence extends over a sector of only 244 deg, slightly larger than the 240-deg sector swept by the cylindrical beam of the near field and part of the transition zone field (see Figures 1-3, p. 1-4, and A-1, p. A-4). Although the power density falls rapidly outside the cylinder containing most of the power, it increases rapidly as the antenna face is approached along the exclusion fence boundary extending radially at 345 deg and at 229 deg. Consequently, in this section we address the power density in Sector 3 (Figure 3-1, p. 3-3) from 1,000 ft to as close as 200 ft. In this part of sector 3, shown in Figure 3-9, the power density varies with azimuth, falling to essentially zero at the 317-deg and 257-deg radials that bound Sector 3. The power density in this region is characterized by the calculated values, for ground level, given in Table 3-1. The radials selected are along the exclusion fence and the mid-line of each part of Sector 3. At the limits of public access posed by the security fence, about 350 ft from array center on the northwest and 250 ft on the southwest, the power density is calculated to be 42 and 90 microwatts/$cm^2$, respectively. Measurements have been made to verify these estimates (see Figure B-4, p. B-13). The largest power density measured in this part of sector 3, outside the security and exclusion fences, was about 50 microwatts/$cm^2$.

Table 3-1

CALCULATED POWER DENSITIES ALONG SELECTED RADIALS IN SECTOR 3

| Distance from Array Center (ft) | Power Density (microwatts/$cm^2$) 345- and 229-deg Radial (along exclusion fence) | 331- and 243-deg Radial (mid-sector) |
|---|---|---|
| 1,000 | 3.9 | 1.3 |
| 800 | 6.5 | 2.2 |
| 600 | 12 | 4.2 |
| 400 | 30 | 11 |
| 350 | 42 | 15 |
| 250 | 90 | 33 |
| 200 | 150 | 58 |

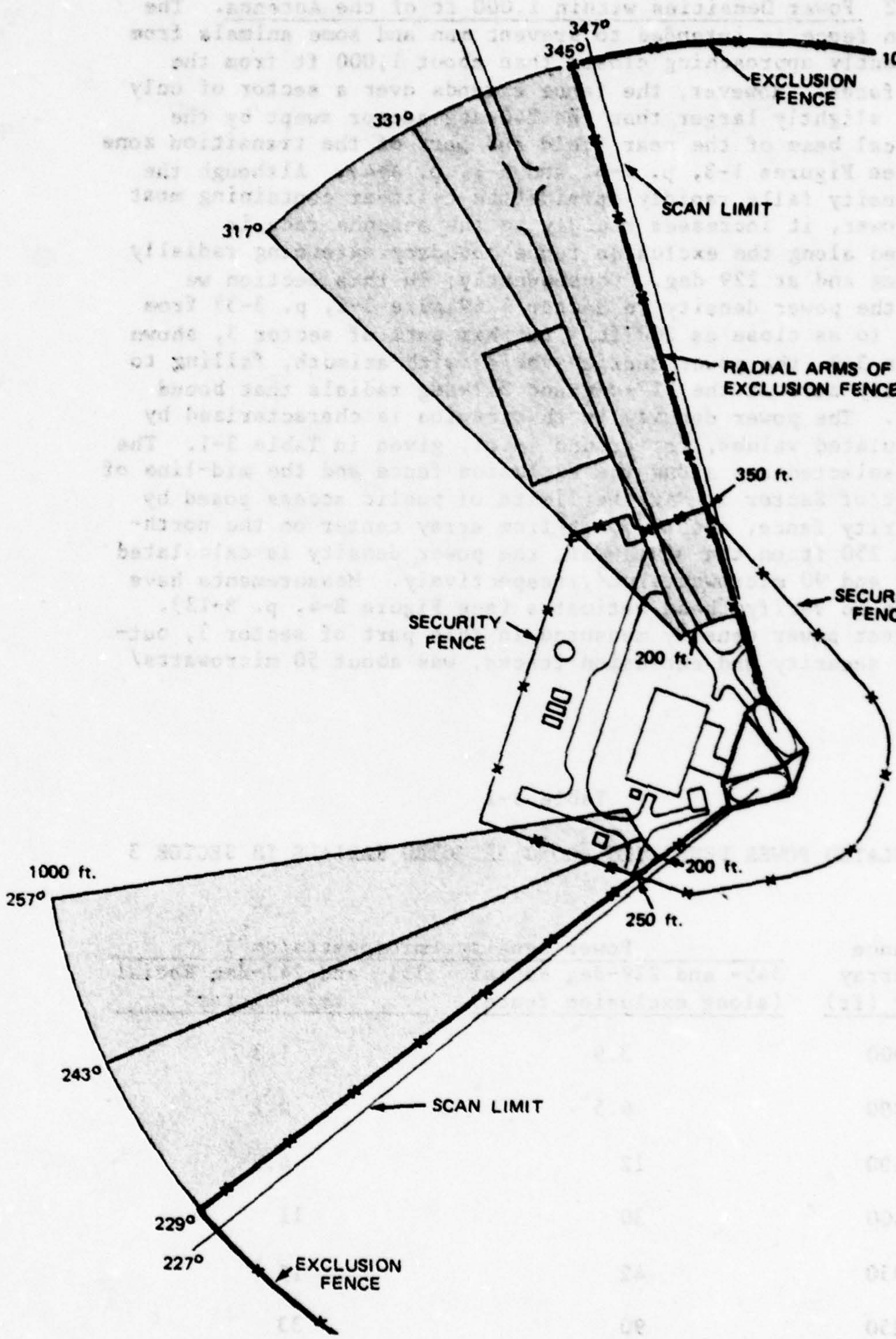



FIGURE 3-9. SECTOR 3 AT CLOSE RANGE, 200 TO 1000 FEET

### 3.1.1.2 EMR Power Densities in Populated Areas

For the convenience of the population near PAVE PAWS interested in the results of the methodology described above, this section describes the numbers and general locations of people and the power densities to which they will be exposed with the PAVE PAWS installation on Flatrock Hill operating. As above, power densities given for each area are estimates based on the calculated free-field radiation pattern from PAVE PAWS; that is, the estimates assume that the power is moving out through space, free of interference by terrain, buildings, or vegetation, which reduce the power density. (Sagamore is an exception; because of terrain, it is in a deep shadow from PAVE PAWS.) Thus, the calculated power density given for each area can be considered an upper estimate, approached but not likely to be exceeded.

Figure 3-1, p. 3-3, shows all the areas in the immediate vicinity of PAVE PAWS. The labeled areas in Figures 3-10 and 3-11 -- enlarged portions of Figure 3-1 -- show major residential areas in relation to the sectors described in Section 3.1.1.1, p. 3-2. The power density and approximate population in each area are given in Table 3-2, p. 3-16. The estimate of power density for each area is not expected to exceed those values because of the following assumptions:

(1) The distance from the radar was taken to be the closest boundary of the area, whereas the power diminishes as one moves farther away from PAVE PAWS within the area.

(2) The elevation of each area was taken to be the highest in the area (to the next highest 50-ft interval), whereas power densities at lower elevations in an area may be lower because of greater distance from the first sidelobe.

(3) Each area was taken to have an unobstructed view of PAVE PAWS, with the exception of the part of Sagamore which is in area G, deeply shadowed by terrain (shown in Figure 3-10). A shadow was assumed to exist only in a location in which a building or tower up to 40 ft high would still be in shadow. There are several small, shadowed areas within Sandwich that were not accounted for in Table 3-2, either because the shadow is too shallow or because they are unpopulated. In defining shadow areas, only terrain was taken into account. In reality, intervening buildings or trees also would reduce the power density to some extent (see Section 4.4.2, p. 4-20).

Population figures for the town of Sandwich were obtained from the January 1978 street list, which accounts for everyone 17 years of age and older. Population for Sagamore was obtained from a town selectman (Johnson, 1978). The total year-round population in each area was estimated by adding the number of students (i.e.,

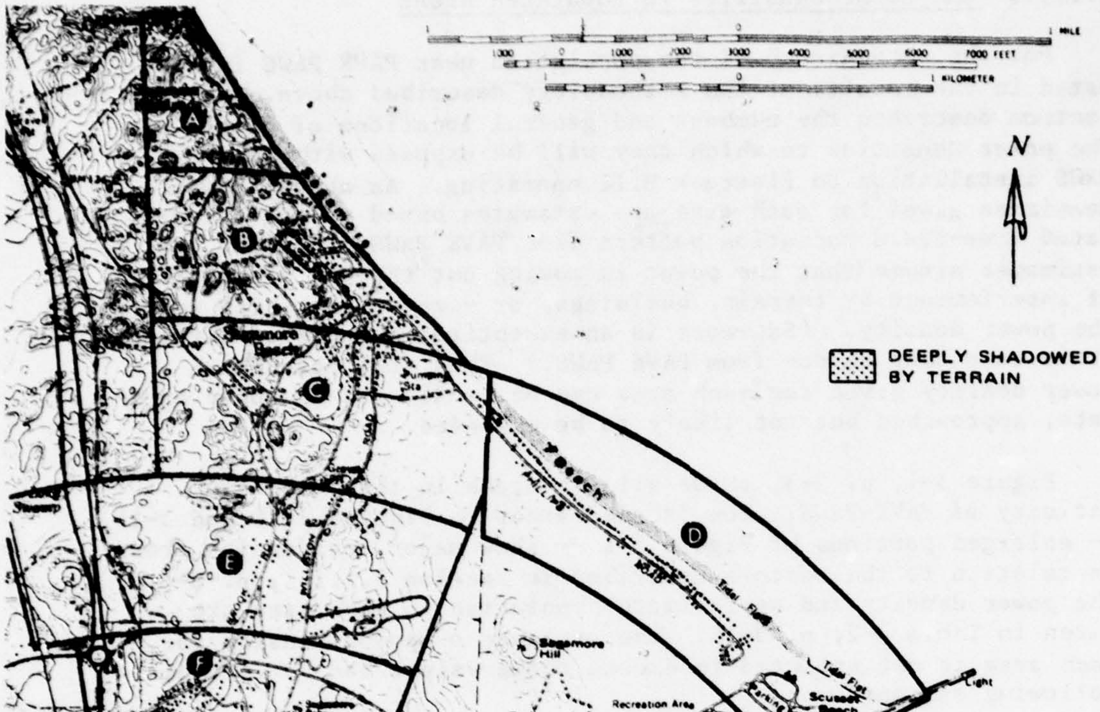



FIGURE 3-10. POPULATED AREAS NORTH AND EAST OF FLATROCK HILL

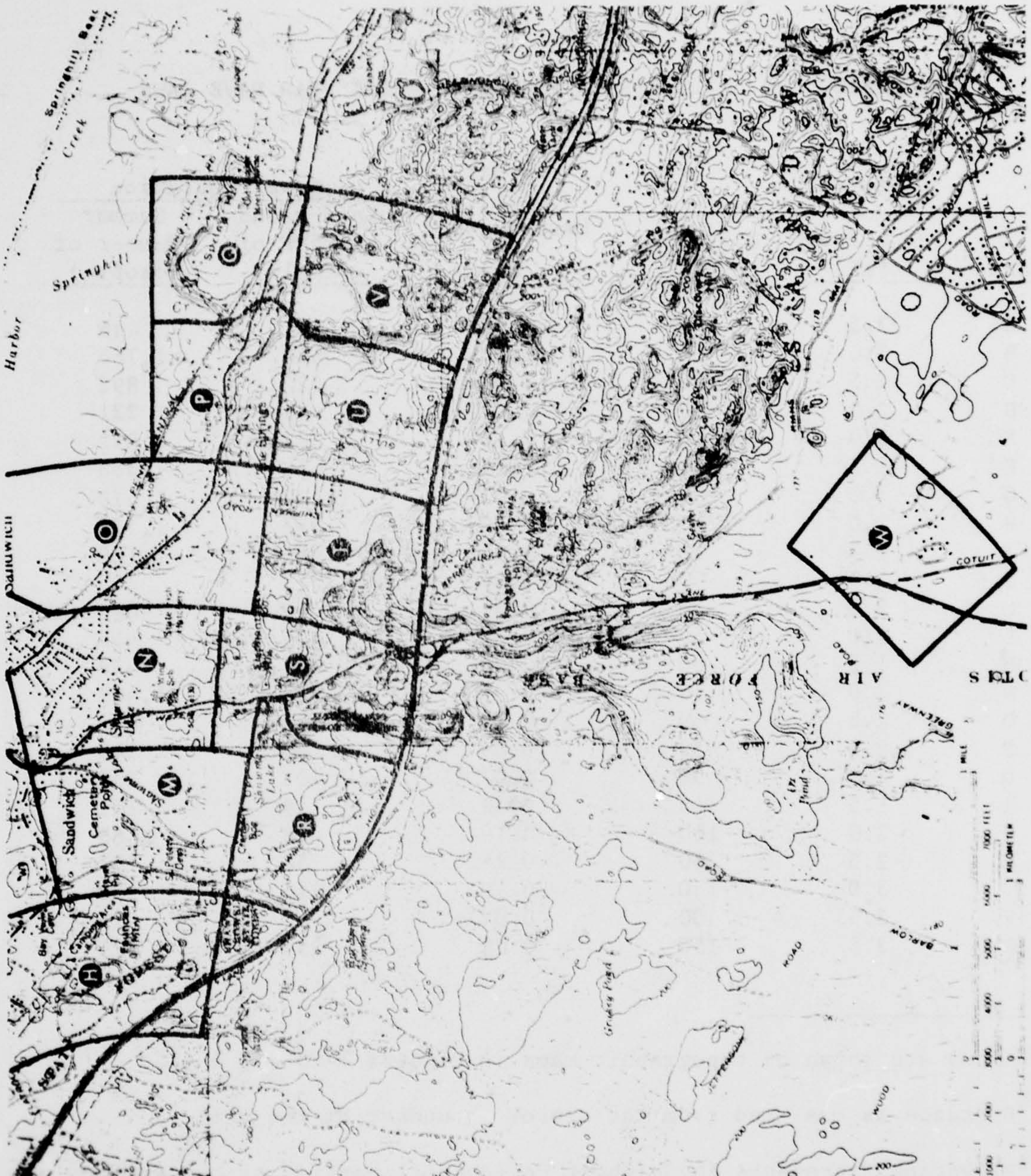



FIGURE 3-11. POPULATED AREAS EAST AND SOUTHEAST OF FLATROCK HILL

Table 3-2

CALCULATED EMR EXPOSURES IN POPULATED AREAS NEAR PAVE PAWS

| Area[a] | Distance from PAVE PAWS[b] (mi) | Elevation[c] (ft) | Power Density[d] (microwatts/$cm^2$) | Area Population | |
|---|---|---|---|---|---|
| | | | | Year-round (Number of people) | Summer (Number of people) |
| A | 3.5 | 100 | 0.05 | 161 | 446 |
| B | 3.0 | 50 | 0.06 | 644 | 1,785 |
| C | 2.5 | 100 | 0.08 | 322 | 892 |
| D | 2.5 | 0 | 0.06 | 85 | 221 |
| E | 2.0 | 100 | 0.11 | 322 | 892 |
| F | 1.5 | 50 | 0.14 | 484 | 1,338 |
| G | 1.0 | 100 | 0.03[e] | 1,290 | 3,570 |
| H | 1.0 | 100 | 0.32 | 587 | 1,526 |
| I | 1.5 | 50 | 0.14 | 446 | 1,160 |
| J | 2.0 | 50 | 0.09 | 275 | 715 |
| K | 2.5 | 50 | 0.07 | 342 | 889 |
| L | 2.0 | 50 | 0.09 | 175 | 456 |
| M | 1.5 | 50 | 0.28 | 169 | 439 |
| N | 2.0 | 50 | 0.17 | 573 | 1,489 |
| O | 2.5 | 50 | 0.12 | 184 | 478 |
| P | 3.0 | 50 | 0.09 | 40 | 140 |
| Q | 3.5 | 50 | 0.07 | 102 | 265 |
| R | 1.5 | 150 | 0.32 | 39 | 101 |
| S | 2.0 | 100 | 0.19 | 26 | 68 |
| T | 2.5 | 150 | 0.15 | 58 | 151 |
| U | 3.0 | 150 | 0.10 | 215 | 559 |
| V | 3.5 | 100 | 0.07 | 5 | 13 |
| W | 3.5 | 150 | 0.08 | 258 | 671 |

[a] Areas are shown on topographic maps in Figures 3-10 and 3-11.

[b] Distance is measured from the closest boundary of the area.

[c] Elevation represents the highest residential portion of the area.

[d] These values represent the calculated upper estimate of the long-term average power that would be received in each area. (See Section 3.1.1.2, p. 3-13, for a discussion of assumptions made for this calculation.)

[e] This area is in deep shadow (see text) and thus is estimated to experience a power density a factor of 10 lower than otherwise.

people under 17 years of age) according to the town-wide ratio of students to people 17 years old or older. Summer population was estimated assuming a ratio of 2.6 summer residents per year-round resident, based on population figures in the Water Quality Management Plan/EIS for Cape Cod (1978).

The Mid-Cape Highway (Route 6) just south of Sagamore offers the closest routine public access to Flatrock Hill, and thus the highest power density to which the general public would routinely be exposed. Figure 3-12 shows the approximate power densities that would be experienced by people riding onto the Cape on Route 3 from Long Swamp (north of the Sagamore Bridge), crossing the Sagamore Bridge, and driving on Route 6 to Interchange 2 (south of Sandwich Center). Again, the estimate is high because the vehicle occupants are assumed to be unshielded by terrain, vegetation, or the vehicle.

An estimate of power density at any specific location within 25,000 ft (approximately 4.5 mi) of PAVE PAWS may be obtained using the procedures of Section 3.1.1.1, p. 3-2. (For distances greater than 25,000 ft, see Section A.3.3, p. A-14.) For example, the Wing School, in area N (see Figure 3-11, p. 3-15), is approximately 11,500 ft from PAVE PAWS, at an elevation of 50 ft, and is located in Sector 1. Figure 3-4, p. 3-6, shows power densities for Sector 1 from 5,000 to 25,000 ft from PAVE PAWS. At a distance of 11,500 ft and an elevation of 50 ft, the estimated power density is about 0.15 microwatts/cm$^2$. (The measured value was less than 0.001 microwatts/cm$^2$; see Table B-5, p. B-12.) +

### 3.1.2 Biophysical Impacts

#### 3.1.2.1 Human Health

Because there has been considerable ongoing interest from concerned citizens about human health aspects of PAVE PAWS, this section has been written in a style that is less technical than Appendix C. Appendix C, written in the form of a detailed critical review, including a bibliography, expands on this human health section with specific reference citations. The two sections are organized in parallel, with the letter "C" in the appendix paragraph number equivalent to the paragraph number prefix "3.1.2.1" in this chapter. Specific bibliographic references are not included in this section. ++

The generic term radiofrequency radiation (RFR) has been used to include other terms commonly found in the literature, such as electromagnetic radiation (EMR), nonionizing electromagnetic +

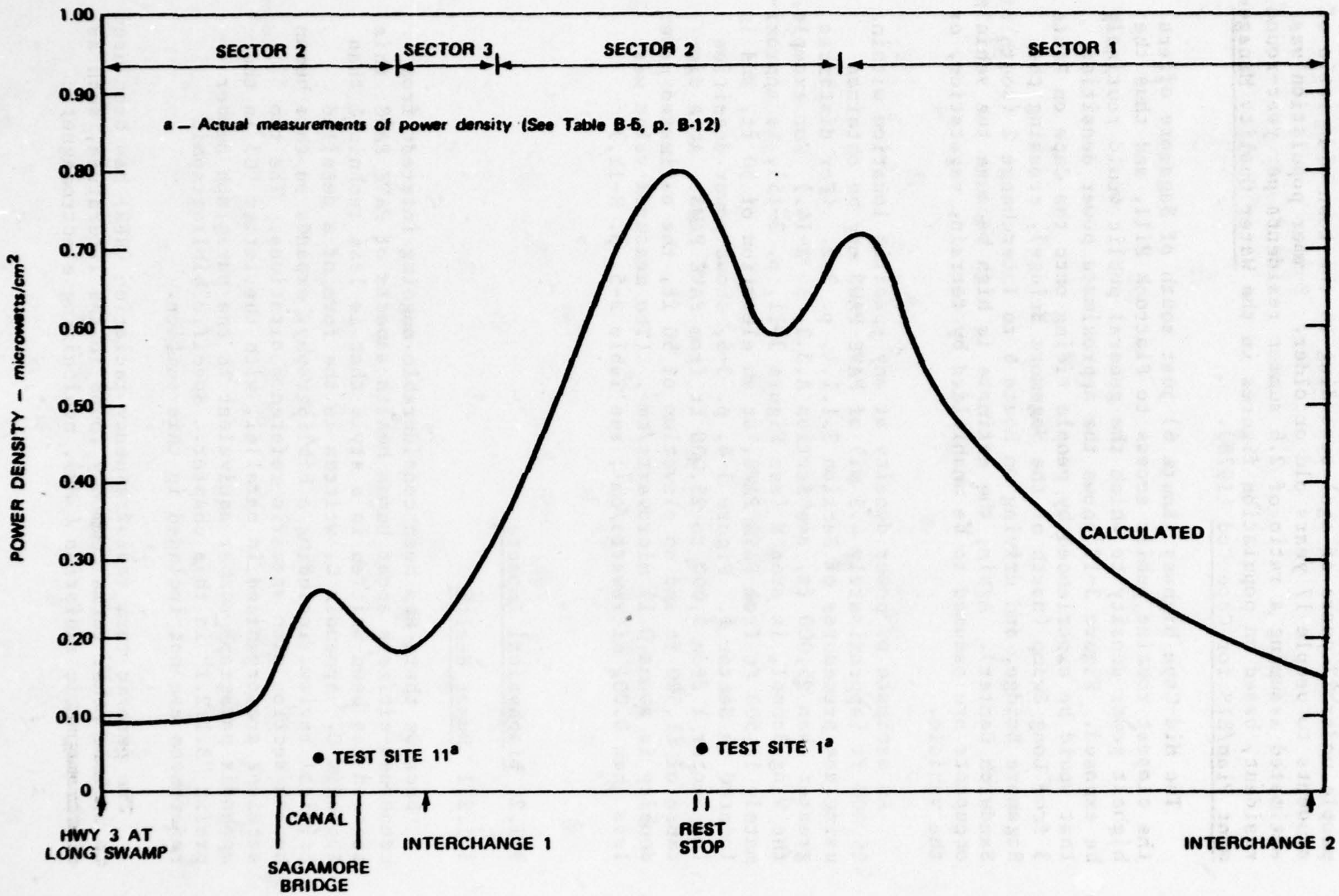



FIGURE 3-12. POWER DENSITY ALONG MID CAPE HIGHWAY FROM LONG SWAMP IN THE TOWN OF BOURNE TO INTERCHANGE 2 IN THE TOWN OF SANDWICH

radiation (NIEMR), microwave radiation, electromagnetic fields (EMF), microwave fields, and others. The term RFR, as used here, is intended to apply to the frequency band from approximately 10 to 18,000 MHz (18 GHz). The PAVE PAWS frequency band is 420 to 450 MHz.

3.1.2.1.1 Introduction. The primary issue addressed in this EIS is whether brief or continual exposure of people to the power densities of RFR produced by PAVE PAWS is likely to adversely affect their health. This issue has been examined in depth by conducting a critical review of the present state of knowledge regarding biological effects of RFR. The review was based largely on the selection and analyses of documents, from the large body of literature on the subject, that are most significant scientifically and pertinent to the operational characteristics of PAVE PAWS and to the power densities of RFR to be encountered in the geographic region around the radar that may be of concern. +

3.1.2.1.1.1 The Problem

Humans can be exposed to the RFR from PAVE PAWS under two circumstances. First, people may be airborne in the vicinity of PAVE PAWS. In this event they may be exposed to the main beam and first sidelobe in addition to higher order sidelobes (see Appendix A for a complete description). Second, populations outside the ++ exclusion area will be exposed more or less continuously to the low-intensity RFR existing near the ground for several miles from the radar. (Possible exposure of individuals within the exclusion area is excluded from consideration because the Site Command will provide appropriate protective and control measures.)

3.1.2.1.1.2 Airborne Exposure ++

Exposure of an airplane to the main beam is a possibility shared with many operational high-power radar systems. However, as far as is known, there is no case of harm to humans from any such incidental exposure, and there is no reason to believe that the PAVE PAWS situation would be significantly different from that of other radar installations in this respect. The threshold for human perception of individual pulses as apparent sound is a pulse power density of about 300,000 microwatts/cm$^2$ (see Section 3.1.2.1.6.1.2, p. 3-34). Based on field calculations (Section A.3.3.1, p. A-14), this value of pulse power density would be exceeded for distances on the axis of the main beam less than about 1,100 ft for the basic system and 2,200 ft for the growth system. There is no experimental evidence that such persons would experience effects ascribable to the pulse repetition rates per se (modulations) from exposures of a few minutes.

The maximum average power densities above ground level are located in the surveillance volume (see Section D.3.2.1.3, p. D-68, for a description). For the basic system, the maximum average power density in the surveillance volume is about 140,000 microwatts/cm$^2$ adjacent to the array faces, 270 microwatts/cm$^2$ at 1,440 ft, and 20 microwatts/cm$^2$ at one mile. In the surveillance volume of the growth system, the values are 142,500 microwatts/cm$^2$ adjacent to the array faces, 275 microwatts/cm$^2$ at 2,850 ft, and 80 microwatts/cm$^2$ at one mile. Again, there is no experimental evidence that persons within an aircraft exposed to the main beam for durations of even a few minutes at these distances would be affected. Moreover, flying closer to the ground and the radar building would constitute a physical hazard unacceptable to the prudent pilot.

Because of these considerations, the likelihood of a biological health hazard to persons in aircraft is considered negligible, and not given further attention in this assessment.

3.1.2.1.1.3 Ground-Level Exposure. For both the basic and growth systems, the calculated average power densities to which the general public may be chronically exposed ("general public exposure") are less than 1 microwatt/cm$^2$; measurements indicate that the actual values of general public exposure are less than 0.1 microwatt/cm$^2$. Members of the public may be exposed to higher power densities for relatively brief intervals if they elect to approach PAVE PAWS along the roads leading to the site or by traversing the off-road area up to the exclusion fence. Referring to Figure 3-2, p. 3-4, at the 1,000-ft radius of the exclusion fence, the calculated maximum average power densities for the basic system are approximately 30 microwatts/cm$^2$ in Sector 1 (defined in Figure 3-1, p. 3-3, as the sector in which the higher-order sidelobes from the two faces overlap), and approximately 15 microwatts/cm$^2$ in Sectors 2 and 3 (in which the sidelobes do not overlap). The measured power density at 1,000 ft in Sector 2 was 10 microwatts/cm$^2$ (see Section B.3.5, p. B-12). Along the boundaries of the radial arms of the exclusion fence (Figure 3-9, p. 3-12) the average power densities increase to 42 microwatts/cm$^2$ at 350 ft and to 90 microwatts/cm$^2$ at 250 ft. These two distances correspond to the locations where the exclusion and security fences meet, representing the points of closest possible public approach. ++

Regarding maximum pulse power densities, the highest values for individual pulses were calculated rather than inferred from mean duty cycles. The results are: 460 microwatts/cm$^2$ at the 1,000-ft exclusion fence and 1,200 microwatts/cm$^2$ at the 250-ft point of closest public approach. Accordingly, the latter value of maximum pulse power density and 90 microwatts/cm$^2$ maximum average power density were assumed for assessing whether the RFR from the basic PAVE PAWS system constitutes a possible health problem to humans. These values are quite conservative because

the actual site measurements were lower than the calculated values for these sites and because realistic long-term exposures are likely to be at fractions of a microwatt/cm$^2$, both pulse and average, because of the rapid decrease in power density with distance from the site.

For the growth option, similar calculations indicate that maximum average power densities of 29 microwatts/cm$^2$ would be obtained at the 1,000-ft radius of the exclusion fence, and 160 microwatts/cm$^2$ at the 250-ft point of closest public approach. The corresponding pulse power densities are approximately 1,160 and 2,400 microwatts/cm$^2$, respectively. Therefore, the latter value of pulse power density and 160 microwatts/cm$^2$ average power density were assumed to be the maxima for the growth system.

3.1.2.1.1.4 Data Base and Literature Selection. Many sources were used in acquiring a working data base for this assessment, including: reference bibliographies provided in previous reviews of the literature; a comprehensive bibliography prepared by U.S. Government personnel; published proceedings of recent seminars and meetings on the biologic effects of RFR; the computerized data base on Biological Effects of Electromagnetic Radiation (BEER file) of the Mead Technology Corporation, Dayton, Ohio; and the compilations of articles published by the Franklin Institute. Consideration was also given to recent symposia on the biological effects of RFR.

Several criteria were used in selecting articles for inclusion in this review. Preference was given to complete papers published in scientific journals or proceedings of scientific symposia. Where details of the procedures and findings were sufficiently clear and complete, abstracts of presentations at recent scientific symposia were also used. Considerations included: the date of publication (more recent articles were preferred because of improvements in the technology of exposure and dose measurement), the frequencies of the RFR (especially frequencies close to those of PAVE PAWS, but also others in the general range from 10 MHz to 18 GHz as appropriate), and the significance of the findings to human health (e.g., studies of human populations to ascertain whether the occurrence of specific effects is statistically higher in population samples exposed to RFR than in similar population samples not exposed, and experiments involving long-term exposure of animals). Other criteria included the relevance of an article to others on the same topic, and possible relevance to concerns expressed by citizens' groups. The number of articles selected was necessarily limited, because of the large number of references on the biologic effects of RFR. However, the articles selected are representative of the entire body of literature on this subject.

3.1.2.1.1.5 Eastern European Bioeffects Literature. Probably the most controversial aspects of research on the biological effects

of RFR are the large discrepancies between results, at low levels of RFR, reported in the Eastern European literature, and those obtained in Western countries such as the United States, and the basic differences in philosophy between the two groups of countries in prescribing safety standards or guidelines for the protection of humans against possible hazards from exposure to RFR. Differences in philosophy of hazard assessment are discussed in more detail in Section 3.1.2.1.3.

From the end of World War II to about the late 1960s, few of the scientific reports on bioeffects research in the USSR (or other Eastern European countries) were amenable to critical review because they lacked essential information. In the early 1970s, starting essentially with an international conference on the bioeffects of RFR in Warsaw in 1973 under the sponsorship of World Health Organization (WHO), international interchanges of information increased materially, and translations of Eastern European articles became easier to obtain. Because most of the Eastern European documents prior to 1973 (and many since then) are merely abstracts that contain no details of the experimental method, number of subjects, or analytical approach used in the study, evaluation of them proved difficult. More recent Eastern European studies contain more detail, and a number of them are cited in the bibliography of Appendix C to this EIS.

The bioeffects literature of the Eastern European countries was evaluated, especially with regard to purported effects at low average power densities, and those of pulsed RFR. Because the average power densities from PAVE PAWS for the general public (calculated to be less than 1 microwatt/cm$^2$, actual measurements show less than 0.1 microwatt/cm$^2$) are smaller than the USSR safety standard of 5 microwatts/cm$^2$ for continuous (24-hour) exposure of the general population, the controversy regarding the large differences in the US and USSR "standards" is not really relevant to the issue of whether the RFR from PAVE PAWS is hazardous to human health.

3.1.2.1.2 <u>Present Climate and Context</u>. Public use of RFR-generating devices and acceptance of their benefits have been growing almost exponentially over a number of years. Public television and radio broadcasting stations, ham radio transmitters, citizens band radios, ground level and satellite communication systems, civil and military aircraft navigation systems, airport traffic control systems, medical diathermy units, defense tracking systems, remote garage door opening devices, microwave ovens, and a variety of units for industrial heating and processing of materials, all contribute to the expansion of RFR in this country. All of these devices are regulated by the Federal government, mainly the Federal Communications Commission, and all are restricted as to what frequency band they may operate in. Most are also restricted as to what power levels they may emit.

Still, with the growing number of devices, the background level of RFR in this country, particularly in urban and industrial centers, is bound to increase, and it is appropriate to ask the question whether this increasing level of RFR will be deleterious to human health.

Various agencies of the Federal government have established programs to deal with the question of effects of RFR on human health. The EPA is conducting a study of environmental levels of RFR. The Bureau of Radiological Health (BRH) has developed a set of standards for permissible microwave oven leakage. The National Institute for Occupational Safety and Health (NIOSH) is investigating use of industrial microwave devices. All three of these agencies, together with the Department of Defense (DOD), maintain research programs on the biological effects of RFR, with the objective of assessing effects on human health. None of the results of this surveillance gives any cause for alarm. Reported biological effects of RFR are largely confined to average power densities of thousands and tens of thousands of microwatts/cm$^2$. Present maximum environmental levels in cities are generally in the range of 0.01 to 5 microwatts/cm$^2$, with the occasional exception of regions in the vicinity of broadcast towers where the environmental levels may range from 10 to higher than 50 microwatts/cm$^2$. Environmental RFR levels of 0.01 to 5 microwatts/cm$^2$ are currently found in the neighborhood of some civilian and military facilities. Surveys of RFR power densities in the vicinity of these facilities have yielded values that are comparable to or greater than those calculated for PAVE PAWS beyond the exclusion fence.

3.1.2.1.3 Problems of Risk Assessment. The issue stated to be most significant in assessing the environmental impact of the PAVE PAWS facility is the question of whether the RFR from the facility will be hazardous to the health of the population in the surrounding region. To consider this issue in its proper context, it is necessary first to define what is meant by a hazard, and second to review the philosophical and scientific principles on which the determination of a hazard might be based.

The term "hazard" as used here does not refer to a scientific investigation or conclusion. It is a judgmental term implying that the probability or risk of certain biological effects of a force or substance is an unacceptable threat to human health, safety, or well-being. Scientific evidence and expertise are crucial to the formal judgment that a hazard exists, but they do not constitute the sole basis of judgment. Hazard determination must also consider other questions, such as: What level of risk is acceptable? Which biological effects should be considered and which ignored? What kinds of and how many people are at risk? What consideration should be given to the rare individual who might be exceptionally sensitive? Who should bear the burden of

proof in determining whether a hazard exists? What are the political, economic, and social consequences of a decision that a hazard exists?

There are no fixed answers to the above questions, and persons who evaluate hazards give varying weight to the different questions, according to circumstances. Two of the questions are of particular importance to this EIS. The first question concerns what level of risk is acceptable. There is no environmental condition to which man may be exposed that is absolutely free of risk. Even natural foods that man has eaten for thousands of years present some risk to certain people and in certain circumstances. The second question concerns which biological effects to consider in evaluating hazard. In this EIS all reported biological effects of RFR have been considered in assessing the potential hazard of PAVE PAWS, but the most careful and detailed analysis has been applied to those effects usually considered to be irreversible and harmful to the individuals affected. ++

A process closely related to hazard evaluation is the setting of exposure standards or limits. An exposure standard is a concentration, intensity, or amount of a substance or force that is believed to pose little or no hazard to the human population. Such a standard does not necessarily imply that exposure at higher levels is harmful, nor does it guarantee that exposure below the standard is absolutely safe for everyone. It is merely a best judgment of an acceptable level for human protection. Setting exposure standards involves answering the same questions as those mentioned above for hazard evaluation. In addition, it is often complicated by the technical problems in estimating the probable dose-effect relationships of a substance in human beings from data obtained in experimental animals.

Standard setting for minimizing hazard is often thought of as a function of legislative bodies, courts, and government agencies. However, in the United States and Western European countries, health and safety standards may also be set by individual corporations for their employees, by insurance companies for their clients, by industries through mutual agreement or negotiation with labor unions, and by other processes. In each case, the considerations for evaluating the hazard differ, and thus the principles for setting the standard are different. The result is that in the United States there is no uniform philosophy which governs the setting of exposure standards, and in various areas of consideration -- food and drugs, chemical manufacturing, mining, air pollution, and others -- different principles are used. In the USSR and the Eastern European countries, by contrast, standards are set by a Council of Ministers, and the philosophy for evaluating the risks and setting the standards is relatively uniform. In this EIS biological effects of RFR are considered ++
from the viewpoint of potential human hazard. However, there is

no attempt to set exposure standards for RFR, and existing or contemplated exposure standards anywhere in the world are not at issue here.

In the USSR, the official maximum permissible average power densities for people occupationally exposed to RFR in the frequency range from 300 MHz to 300 GHz (encompassing the PAVE PAWS frequencies) emitted from stationary antennas are 10 microwatts/cm$^2$ for a full working day, 100 microwatts/cm$^2$ for 2 hours, and 1,000 microwatts/cm$^2$ for 20 minutes. The maximum value for continuous (24-hour) exposure of the general population is 5 microwatts/cm$^2$. The armed forces of the USSR are specifically exempt from this regulation. The process by which these standards were arrived at is unknown because the Council of Ministers does not publish its proceedings. However, the guiding principle for occupational exposure standards in the USSR is that they should be set at a value that will not produce, in any of the persons exposed, any deviation from normal or any disease. "Any deviation from normal," then, bars any biological effect, whether it has significance for health or not, and whether or not it represents a temporary deviation to which the human will readily accommodate. The principle also implies that all persons, including the unusually susceptible, shall be protected by the standards.

The United States has no official maximum permissible exposure limit for RFR for the general population. The Occupational Safety and Health Administration (OSHA) has promulgated a radiation protection guideline (RPG) of 10,000 microwatts/cm$^2$ for persons occupationally exposed for greater than 6 minutes to radiation in the frequency range from 10 MHz to 100 GHz based on the same RPG value of the American National Standards Institute, and this guideline has been adopted by a number of organizations, including the DOD. (Air Force has used the 10,000 microwatts/cm$^2$ occupational standard since the 1960s.) The principle underlying such a guideline is the belief, based on existing scientific evidence, that nearly all workers can be exposed to such a level during the normal series of working days without adverse effect. The guideline recognizes, then, that the RFR might cause biological effects that have no medical consequence, or that the workers could readily accommodate to the effects. Occasionally, workers might also suffer minor adverse effects that could be detected before serious medical consequences developed. However, it is possible that the occupational standard may be revised in the future to include more detailed specifications of frequency-dependent maximum exposure levels related to exposure durations. The question of a need for an environmental limit or standard is still under consideration by the EPA.

Aside from these differences in what kinds and levels of biological effect are considered in formulating exposure standards, another important philosophical difference exists between the USSR and the United States in evaluating environmental and

occupational hazards. Medical theory in the USSR, under the influence of Pavlovian tradition, places strong emphasis on the role of the central nervous system (CNS) in health and disease and uses neurological and behavioral tests extensively for diagnosis and evaluation. Medical theory in the United States strongly emphasizes pathological processes and conditions and tends to restrict attention primarily to those regions of the body where the disease is localized. The relative merits of the two viewpoints is not an issue in this document, but one should note that they can produce different evaluations of the same data and different assignments of risk at the same exposure level.

The analysis of the biological effects in this document generally follows the principle that biological effects reported from exposure to RFR should be examined in the context of the physiological mechanisms involved and the power density levels employed in the experiments. Evidence for the presence or absence of threshold values of power density is particularly important. Finally, although no evidence of potential hazard is totally disregarded, the biological effects of RFR reported in the literature are examined carefully for evidence of scientifically valid performance and interpretation. Unsupported statements of opinion and scientific reports that do not meet reasonable criteria of validity are given little or no weight in the evaluation of hazard.

3.1.2.1.4 <u>Assessment of Scientific Information</u>. Interpreting the available research findings to predict whether RFR from PAVE PAWS is likely to be hazardous to the human population in its vicinity is not a simple process. The most conclusive information would come from studies involving well controlled and carefully specified exposures of people of a variety of ages and states of health to RFR identical to that of PAVE PAWS. Such studies should ideally be carried out by experts and should include full understanding of the physical and biological mechanisms underlying any identifiable effects. This kind of information is not available. The information that is available comes from a variety of studies, none designed specifically to assess the effects of PAVE PAWS, that must be interpreted in the PAVE PAWS context. All of the available information requires some extrapolation or modification to apply it in the assessment of PAVE PAWS. The greater the extrapolation or other modification that is made, the more likely that experts will differ in their interpretation of the available data. A critical problem regarding negative results in scientific studies tends to occur regularly in disputes regarding environmental hazards. A negative result in a scientific study cannot prove the absence of biological effects -- harmful or otherwise -- and any number of repetitions of such a study, with negative results in each case, cannot conclusively prove the absence of effect. Hence, one can never prove that any environmental agent is "completely harmless." Regulatory agencies

and others concerned with public safety are not always in a position to take such a rigid stand, and hence public reviews of environmental hazards often contain statements about possible effects of an agent that are sometimes confused with statements of fact.

3.1.2.1.5 Other Assessments and Reviews. Two other assessments of PAVE PAWS and nine previous reviews on the biological effects of RFR published within the past six years were examined in the course of preparing this EIS. Detailed descriptions of these assessments and reviews may be found in Section C.5, p. C-12. ++

### 3.1.2.1.6 Present State of Knowledge Regarding Physical Effects

#### 3.1.2.1.6.1 Interactions of Fields with Biological Entities.

Interactions of electromagnetic fields with biological entities are often loosely characterized in the bioeffects literature as "thermal" or "nonthermal," a usage that has led to confusion and controversy. Therefore, it is appropriate at this point to introduce working definitions of these terms, with the recognition that the boundary between these types of interaction is not sharp. ++

The interaction of an agent (e.g., RFR) with an entity (biological or nonbiological) can be characterized as thermal if the energy absorbed by the entity is transformed at the absorption site into heat. Heat absorption, in turn, is defined in classical thermodynamics as either an increase in the mean random speed (or kinetic energy) of the molecules at the site (a local increase in temperature), or as an increase in the disorder or randomness of the molecular motion without an increase in mean random speed or temperature (analogous to the process involved in ice melting at 0° C), or both. ++

An entity can also absorb energy at specific discrete frequencies in the form of energy packets or "quanta," each of which has an energy proportional to one of the discrete frequencies. The constituents and configurations of the various molecular species comprising the entity determine the specific frequencies or characteristic spectra at which such absorption can occur. The kinds of interactions involved are numerous and of varying degrees of complexity. They include alterations of molecular orientations and configurations that do not change the basic identities of the molecules, disruption of intermolecular or intramolecular bonds, and excitation of atoms or molecules to higher electron states (including ionization). Such interactions can be characterized as "short-range" processes. There are also cooperative interactions among subunits of molecules within biological cells, in cell membranes, and in extracellular fluids. ++

Cooperative interactions are often characterized as "long-range" because absorption of energy at one specific site in a structure, e.g., in a membrane or in a biological macromolecule, can affect a process elsewhere in the structure, or a function of the structure as a whole can be triggered by the release of energy stored in the structure, thereby producing biological amplification.

Conceptually, all such quantum interactions can be ++
characterized as nonthermal. However, if most of the energy thus absorbed is subsequently transformed locally into heat (as defined above), then the distinction between nonthermal and thermal is blurred. Pragmatically, therefore, characterization of an interaction of RFR with a biological entity as nonthermal requires that the interaction give rise to a frequency-specific effect that is experimentally distinguishable from heating effects due to thermalization of the absorbed RFR energy.

### 3.1.2.1.6.1.1 Thermal Effects of Time-Averaged Power Density and Dose-Rate Considerations; Nonthermal Effects of CW RFR

Consider now the effects of CW RFR on a human or an animal. ++
The relative magnetic permeability of most organic constituents is about unity. Therefore, thermal interactions (as defined above) can be described in terms of the dielectric, electrical-conductivity, and thermal properties of the bodily organs, tissues, fluids, and so forth, as well as the characteristics of the RFR (frequency, power density, polarization). Measurements of these properties have been made for various mammalian tissues, blood, cellular suspensions, protein molecules, and bacteria over the frequency range from about 10 Hz to 20 GHz. In the subrange from about 300 MHz to about 10 GHz, the dielectric constant of such constituents as skin, muscle, and blood vary little with frequency, and the differences in values among such constituents are largely due to differences in water content. In addition, electrical conductivity increases slowly with frequency in this subrange.

Because the index of refraction of any material is related to +
its dielectric constant, RFR is reflected and refracted at +
boundaries between regions of differing dielectric properties, such as at the surface of a body (whether organic or inorganic), for the same physical reasons as for light at a glass-air interface. Thus, RFR at normal incidence to a relatively thick planar specimen is partially reflected at the surface, and the fraction of the power density entering the specimen suffers progressive attenuation with depth because of energy absorption. The concept of "penetration depth" is often used. For homogeneous specimens, the penetration depth is defined as the distance at which the electric field strength is about 37% of its value or the power density is about 14% of its value just within the surface, and the numerical values depend on the electrical properties of

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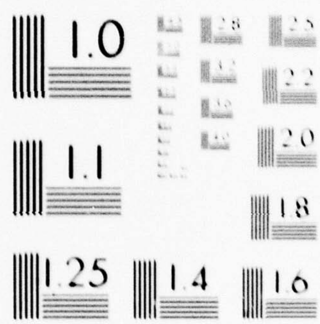


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

the material. Both the reflection ratio and penetration depth vary inversely with frequency. At 450 MHz, about 65% of the incident power density is reflected at the air-skin interface and the penetration depths for skin, muscle, and blood are about 3 cm (1.2 in) and is about sixfold larger for fat. Therefore, the 35% entering the body passes through the skin and its underlying fat layer into the muscular tissue with relatively little attenuation. At 100 kHz, the penetration depths of all constituents are quite large, but the reflection ratio is essentially 100%. On the other hand, at approximately 10 GHz and higher, a somewhat smaller fraction of the incident power density than at 450 MHz is reflected, but penetration is largely confined to the skin.

In the RFR-bioeffects literature, the rate of energy absorption by a small region or sample divided by its weight is called its Specific Absorption Rate (SAR) and is expressed in terms of W/kg or mW/g. The numerical value of SAR in any small region within a biological entity depends on the characteristics of the incident RFR (power density, frequency, polarization) as well as on the properties of the entity and the location of the region. In general, therefore, the spatial variation of SAR within a biological entity is dependent on the attenuation characteristics of its constituents and on the reflection ratios at the interfaces between dissimilar constituents. For biological entities having complex internal distributions of constituents, spatial variations of SAR are not readily calculated. Therefore, the concept of "mean SAR," representing the spatial average value for the body per unit of incident power density, is often used because it is a quantity that can be measured experimentally (e.g., by calorimetry), without requiring knowledge of the internal SAR distribution.

Many investigators have studied relatively simple geometric models, including homogeneous and multilayered spheroids, ellipsoids, and cylinders, having weights and dimensions approximately representative of various species, including humans. Such models were assumed to be or were actually exposed to linearly polarized plane waves, to determine the dependence of mean SAR on frequency and orientation relative to the polarization direction of the RFR. An important result of this work is that the largest mean SAR is obtained when the longest dimension of each kind of model is parallel to the electric component of the field and when the wavelength of the incident radiation is about 2½ times the longest dimension. The adjective "resonant" is often applied to the frequency corresponding to this wavelength. For circularly polarized RFR (the type of polarization used in PAVE PAWS), resonances of this kind would also occur. However, the major contribution to the resonant mean SAR values would be from only half the incident power density, because circularly polarized RFR can be regarded as consisting of two equal, mutually perpendicular, linearly polarized components, only one of which would be parallel to the largest dimension of the body. The SAR contribution of the other

component would depend on the body dimension parallel to that component.

Based on prolate-spheroidal models (and linearly polarized RFR), the resonant frequency for an "average" man, approximately 5 ft 9 in tall (1.75 m) and weighing about 154 lb (70 kg) is about 70 MHz; at this frequency the mean SAR is about 0.2 W/kg for 1,000 microwatts/cm$^2$ incident power density, or about 1/6 of his resting metabolic rate, or about 1/21 to 1/90 of his metabolic rate when performing exercise ranging from walking to sprinting. An alternative interpretation of this mean SAR value is that exposure to 1,000 microwatts/cm$^2$ for, say, 1 hour would produce a mean temperature rise of about 0.2 deg C in the absence of any heat-removal mechanisms. However, actual temperature increases would be lower or even zero because physical heat-exchange mechanisms (conduction, convection, radiation) are always present, and for mammals (and other warm-blooded species) these mechanisms are controlled by thermoregulatory systems.

Similarly, the resonant frequency for an "average" woman about 5 ft 3 in tall is about 80 MHz, and her mean SAR is about the same as for the average man. The resonant frequency of a 10-year-old is about 95 MHz; for a 5-year-old, about 110 MHz; and for a 1-year-old, about 190 MHz. The mean resonant SAR values for such children are about 0.3 W/kg for 1,000 microwatts/cm$^2$.

If a model human were to be standing on a wet surface or near other electrically conductive surfaces (reflectors), the resonant frequency would be lower and the mean SAR (at the lower resonant frequency) would be higher. However, because the values of incident power density from PAVE PAWS at ground level beyond the exclusion area are much lower than 1,000 microwatts/cm$^2$ and its operational frequencies are considerably higher than the resonant frequencies in either the absence or presence of nearby reflecting surfaces, no changes in body temperature would be expected.

The foregoing discussion of mean SAR is also largely applicable to pulsed RFR (and other types of modulated RFR) at corresponding carrier frequencies and time-averaged incident power densities. (However, as discussed in the next section, there are several differences in interaction between CW and pulsed RFR.)

Because RFR can also be refracted at the air-surface and internal interfaces between dissimilar constituents, internal convergence is possible under certain conditions, notably for convex entities of dimensions that are comparable with the wavelength of the incident field; the action somewhat resembles the convergence of light by a lens. Therefore, despite the attenuation with depth mentioned above, there may be internal regions at which the local SAR values are higher than at the surface facing the source. For convenience, such internal local regions of relative maximum SAR have been dubbed "hot spots," even for

combinations of incident power density and exposure duration that would produce biologically insignificant temperature rises at such spots.

The conditions under which hot spots could occur within the head were studied by a number of investigators, using homogeneous and multilayered spherical models. They found that hot spots can occur only with specific head-diameter and frequency domains; i.e., for heads less than about 16 cm (6 in.) in diameter and for frequencies between about 300 MHz and 12 GHz, the sizes of these two domains being interrelated. To cite a specific example relevant to PAVE PAWS: for a head about 10 cm (about 4 in) in diameter, the hot spots are internal over the frequency range from approximately 400 MHz to approximately 3 GHz, with the highest relative maximum SAR occurring at about 1 GHz. Above and below this frequency range, the maximum SAR is at or just beneath the surface facing the source; as the frequency is increased from 400 MHz, the hot spots shift inward and then outward toward the source because of the decrease of penetration depth with frequency. At 450 MHz, the hot spot is close to the front surface and its SAR is about 15% larger than the front-surface SAR at 400 MHz. However, for a head 20 cm (about 8 in) in diameter (about the size of an adult human head), there are no internal hot spots at any frequency; the maximum SAR values are always at or just within the surface facing the source.

Results of theoretical analyses of such relatively simple geometric models have been verified experimentally by constructing physical models from synthetic biological materials (having approximately the same electromagnetic characteristics as their corresponding biological constituents), exposing such models to sufficient power densities to obtain readily measurable temperature rises, and measuring such temperature rises immediately after exposure. Although much useful information has been obtained in this way, human and animal configurations are far more complicated and different from one another. Therefore, SAR distributions in animal carcasses and figurine-shaped physical models have been determined experimentally.

Among the qualitative results of general interest obtained with human figurines are that, at frequencies near resonance, the local fields can be much higher for certain regions such as the neck and groin than for other body locations, and that field distributions for nonprimates are quite different from those for primates, a point that should be given proper consideration when endeavoring to extrapolate experimental bioeffects findings on any laboratory animal species to humans or to compare experimental results on one laboratory species with those on another species. However, the PAVE PAWS frequencies are much higher than the human resonance values (e.g., 70 MHz for the model average man) and the corresponding mean SAR values are considerably lower than the resonance values (e.g., about 0.026 at 450 MHz versus 0.2 at 70

MHz). Consequently, for the reasons stated previously, local temperature rises in body regions such as the neck and groin would be negligible for the power densities beyond the exclusion area.

For the short-range quantum interactions (as defined above) of CW RFR, the discrete frequencies are in the infrared range from about 19,000 to 240,000 GHz, and the lower end of this range is about 42,000 times higher than a quantum of RFR at 450 MHz. Conversely, the quantum energy of 450-MHz radiation is too low (by a factor of 50,000 or more) for such interactions. Therefore, the existence of nonthermal biological effects of CW RFR ascribable to such short-range molecular interaction mechanisms is extremely doubtful.

Biological generation of fields such as brain waves, which have frequencies in the ELF range (below 100 Hz), is regarded as evidence for the occurrence of cooperative or long-range interactions. Theoretical models of nerve-cell membranes indicate that the frequencies for cooperative processes can be much lower than those for short-range interactions. Because the thermal energy corresponding to the physiological temperature $37^{\circ}$C ($98.6^{\circ}$F) is more than adequate for spontaneously triggering cooperative processes, the question has been raised whether theoretically postulated effects of weak RFR would be distinguishable from such spontaneously induced effects. Alternatively, separation of such RFR interactions from thermally triggered interactions may require that the effects of the former exceed those of the latter, implying the existence of a threshold. However, the theoretical considerations for these and many other factors on both sides of this issue are as yet highly speculative. Experimental effects ascribed to such cooperative processes have been reported in preparations of excised tissue exposed to brain-wave frequencies, notably the lower calcium efflux from brains removed from newly hatched chicks, incubated in physiological solution, and exposed to fields in the ELF range. This effect was not observed with CW (unmodulated) RFR at 147 MHz or 450 MHz; however higher calcium efflux was reported for 147 MHz and 450 MHz modulated at frequencies in the ELF range (as discussed in the next section).

#### 3.1.2.1.6.1.2 Interactions of Pulsed RFR and Nonthermal Effects

Precise usage of the term CW RFR implies the presence of only a single frequency (and unvarying incident power density). Because of the time variations of power density and frequency in pulsed RFR (and other forms of modulation), possible biological effects ascribable to the pulse characteristics per se rather than to the time-averaged power density must also be considered.

The interactions of individual RFR pulses with an entity (biological or nonbiological) are analogous to those of mechanical impulses, an impulse being defined as the sudden application of a

force to an entity for a brief time interval, resulting in an abrupt increase in momentum. The total energy imparted to the entity depends on the magnitude of the force and the duration of its application. The interaction can be characterized as nonthermal or thermal, depending on the properties of the entity that determine the disposition of the energy. The impact of a piano hammer on a string, which excites the string into vibration at its discrete resonant frequencies (the fundamental frequency and integer-multiples thereof or harmonics) is an example of an essentially nonthermal interaction as defined previously; most of the energy is transformed into sound, which is converted into heat elsewhere.

A sudden blow to an entity such as a block of material having a set of resonant frequencies that are not necessarily harmonically related to one another will excite many of these frequencies; this illustrates the principle that an impulse contains a broad spectrum of frequencies. The results of an impact on a church bell can be characterized as nonthermal for the same reason as that given for the piano string. By contrast, the effects of a blow to a block of lead or asphalt are essentially thermal; even though some sound is produced, most of the energy is converted into heat on the surface of impact.

One impulse effect of RFR known to occur in humans and animals is the phenomenon of "microwave hearing" or the perception of single or repetitive short pulses of RFR as apparently audible clicks (also discussed in Section 3.1.2.1.7.5.1, p. 3-47). The interaction mechanisms involved are not yet completely understood. However, almost all of the experimental results tend to support the theory that pulse perception occurs because of transduction of the electromagnetic energy into sound pressure waves in the head and normal detection by the auditory apparatus. In one group of suggested mechanisms, transduction is postulated to occur at a boundary between layers having widely different dielectric properties (e.g., at the boundary between the skull and the skin or dura). The energy in a pulse arriving at such a boundary is converted into an abrupt increase in momentum that is locally thermalized; the resulting volumetric temperature rise can be negligible, but the temperature gradient across the boundary (rate of change of temperature with distance) can be large. Under such conditions, rapid local differential expansion would occur, giving rise to a pressure (sound) wave. Thus, whether to characterize this phenomenon as thermal or nonthermal on the basis of such interaction mechanisms is not clear. However, this effect is often characterized as nonthermal because the power density averaged over two or more pulses can be miniscule. For example, consider the arrival and perception of a single pulse of 20-microseconds duration and pulse power density of 1,000,000 microwatts/$cm^2$. If a second pulse of the same duration and power density arrives and is perceived, say, 10 seconds later, the time-averaged power density for these two pulses would be only 2

microwatts/$cm^2$, whereas it would be half this value if the second pulse arrives 20 seconds later. Therefore, the time-averaged power density has no relevance to the perception of the pulses.

Irrespective of how the microwave hearing phenomenon is characterized, the significant point is that most of the experimental results indicate that the pulses are perceived as actual sound rather than by direct RFR stimulation of the auditory nerves or the brain. ++

In typical experiments with human volunteers exposed to pulsed RFR (at 3 GHz), pulse durations of the order of 10 microseconds and minimum pulse power densities of 300,000 microwatts/$cm^2$ were needed for perception. Therefore, this phenomenon should not be a source of concern about PAVE PAWS because the pulse power densities at ground levels outside the PAVE PAWS exclusion fence are less than 1,200 microwatts/$cm^2$ for the basic system and 2,400 microwatts/$cm^2$ for the growth system, or at least two orders of magnitude lower than the thresholds for human perception. ++

Periodically pulsed RFR constitutes a particular type of amplitude-modulated RFR in which the pulse repetition rates are the primary modulation frequencies. Biological effects ascribable to modulation frequencies per se (as distinguished from those due to individual pulses) have been postulated. The occurrence of such effects would require the existence of some nonlinear interaction mechanism to separate the modulation frequencies (rectify the modulated RFR waveform and filter out the carrier frequency). Although the nonlinear mechanisms of interaction underlying this phenomenon are conjectural, the aforementioned results on calcium efflux from chick brains exposed to ELF-modulated 147 MHz or 450 MHz RFR (and the absence of this effect for unmodulated RFR at these frequencies) are regarded as experimental evidence for the occurrence of modulation effects. These results are relevant to PAVE PAWS (especially those with modulated 450 MHz) because the pulse repetition rates of PAVE PAWS are approximately the same as the modulation frequencies used in these experiments. In brief, the calcium efflux reported for chick-brain hemispheres exposed to 147 MHz modulated at frequencies between 6 and 20 Hz was higher than that reported for control hemispheres. The incident average power density was 800 microwatts/$cm^2$, and the effect was largest at 16 Hz. Higher calcium efflux was also obtained with 16 Hz-modulated 450 MHz RFR at incident average power densities in the range from 100 to 1,000 microwatts/$cm^2$ but not below or above this range, indicating the existence of a power-density "window." Preliminary results of increased calcium efflux from the cerebral cortex of the paralyzed awake cat exposed to 450 MHz modulated at 16 Hz were reported in 1977 for an incident average power density of 375 microwatts/$cm^2$. The calculated maximum time-average power densities from the basic PAVE PAWS system at ground level outside ++

the exclusion fence, i.e., 90 microwatts/cm$^2$ at the 250-ft location of closest possible public approach and 30 microwatts/cm$^2$ at the 1,000-ft exclusion fence, are below the average power densities for the chick-brain and preliminary cat-brain results. Thus, there is no evidence that similar effects would occur in humans exposed to the RFR from the basic system at ground levels outside the exclusion fence. This statement is also applicable to the growth system beyond the 1,000-ft exclusion fence, where the maximum average power density is 29 microwatts/cm$^2$; the region along the entire northwest radial arm of the exclusion fence; and the region along the southwest radial arm from 1,000 ft to about 325 ft, in which the calculated average power density increases to 100 microwatts/cm$^2$ (the lower limit of the power-density window for the chick-brain results). Along the segment from about 325 ft to the 250-ft location of the point of closest public approach, the calculated average power density increases from 100 to 160 microwatts/cm$^2$. The latter value is within the power-density window for the chick-brain results but is below the 375 microwatts/cm$^2$ for the cat-brain results. Thus, the evidence to date does not permit adequate assessment of whether the growth system could cause similar effects in humans exposed within this small area along one part of the exclusion fence. However, measurements on the basic system in this small area have indicated actual levels only 60% of the calculated values.

3.1.2.1.6.2 RFR Instrumentation and Measurements

3.1.2.1.6.2.1 Instrumentation. Much of the early laboratory research on bioeffects of electromagnetic fields suffered from lack of adequate instrumentation for measuring incident fields or energy absorption rates; therefore, many of the early results can be questioned, at least from a quantitative standpoint. During the last decade, however, major advances have been made in instrumentation for determining both incident-field intensities for biological research and internal energy-absorption rates.

Instruments are now available for measuring average power densities. These meters span the range from 10 MHz to 18 GHz, are +
isotropic in response, and do not perturb the incident RFR to a significant extent or yield readings containing significant errors due to spurious responses to RFR (e.g., pickup by the lead wires +
from the sensors). The most sensitive range of these instruments provides full-scale readings of about 200 microwatts/cm$^2$. Their response times are about 1 ms or longer, so they cannot be used +
for measuring pulse power densities of short pulses. Therefore, incident pulse power densities are usually calculated from measurements of average power density and duty cycle (or pulse duration and pulse repetition frequency). The use of sophisticated equipment for directly measuring pulse power densities at low average power density, such as the calibrated

instrumentation employed for measuring the fields from PAVE PAWS, is the exception.

Magnetic-field probes have been developed, but only for relatively low frequency ranges, as exemplified by two devices developed at NBS for near-field measurements in the Industrial, Scientific, and Medical (ISM) bands within the range from 10 to 40 MHz with free-space equivalent power density ranges as sensitive as 10,000 microwatts/cm$^2$.

Recently developed implantable or insertable probes for measuring RFR-induced temperature changes or local fields within biological entities during exposure have diminished, to a large extent, problems such as perturbation of the temperature or local field or readout errors ascribable to the presence of the sensor and its lead wires. However, the relevance of such developments to the PAVE PAWS analysis is peripheral at best, because temperature changes due to the power densities from PAVE PAWS will be negligible, even at so-called hot spots within biological entities. This brief mention is included here in the context that such devices were not available or used in most of the bioeffects research to date but are expected to be more widely used in future research.

Also of peripheral relevance to the PAVE PAWS analysis are current developmental efforts toward reducing errors and artifacts in the measurement, during exposure, of biologically generated fields and potentials, such as the electroencephalogram (EEG) and electrocardiogram (EKG).

3.1.2.1.6.2.2 <u>Measurements of RFR Power Densities in Selected Cities</u>. The EPA is measuring environmental field intensities at selected locations within various U.S. cities to permit estimations of cumulative fractions of the total population being exposed at or below various power-density levels. A recent report discusses the results for 12 cities (a total of 373 sites). The field intensities at each site were measured at 21 ft above ground level.

The measured average power densities, integrated over the frequency bands included in the analyses (i.e., from 54 to 890 MHz), ranged from about 0.001 to 2.5 microwatts/cm$^2$, the FM band (88-108 MHz) being the major contributor. The total power density measured at any given site is the result of RFR from many sources at different distances and in different directions from the site. EPA used the site measurements in a computer program to estimate power-density values at other locations. It then derived an estimate of the population-weighted median exposure value for the city; the median exposure value indicates that half of the city's population is being exposed at or below that power density (assuming a static population distribution). These median exposure values range from

0.002 microwatts/$cm^2$ (for Chicago) to 0.020 microwatts/$cm^2$ (for Portland, Oregon), and the population-weighted median for all 12 cities is 0.0053 microwatts/$cm^2$. Also, the calculations showed that approximately 99% of the population studied is potentially exposed to 1 microwatt/$cm^2$ or less, or conversely that 1% is being exposed to more than 1 microwatt/$cm^2$.

Although the values above may be of some interest for possible comparison purposes, the method used for estimating power density values at unmeasured locations is not appropriate for PAVE PAWS because the radar constitutes a single source. Instead, the calculations of power densities and their verification by field measurements, discussed in Appendices A and B of this document, provide more direct and accurate data for statistical analyses of population exposure to the RFR from PAVE PAWS. + + +

### 3.1.2.1.7 <u>Present State of Knowledge Regarding Biological Effects</u>

3.1.2.1.7.1 <u>Epidemiology</u>. Epidemiology, as used in the context of this document, refers to assessments of the effects of exposure to RFR on groups of humans. Although epidemiological data eliminate the need for extrapolation from animal data to the human situation, epidemiologic information tends to be imprecise in other ways (Section C.4, p. C-9). It is usually based on imprecise estimates of exposure characteristics (frequency, power density, and duration). The extent to which the control group matches the exposed group is sometimes open to question. Because matching on all relevant factors except exposure is the basis for concluding that any observed differences between the groups are related to the RFR exposure, selection of an appropriate control group is critical.

Ten recent reports representing different points of view were selected for review -- five from the United States, one each from Poland and Czechoslovakia, and three from the USSR. They provide a representative sample of the kinds of information currently available.

In an earlier study of the causes of mongolism in U.S. children, an apparent correlation was found between this inherited condition and exposure of the fathers of affected children to RFR before the conception of the child. However, after expanding the original study of 216 pairs to 344 pairs of children with mongolism, each matched with a normal child of the same sex born at about the same time whose mother was about the same age, no such correlation was found. Thus, the earlier conclusion, based on a smaller sample, that exposure to RFR contributed to mongolism in offspring, was not confirmed. No quantitative assessment of the extent of the father's exposure was possible.

The causes of mortality in World War II U.S. Navy personnel are being monitored in an attempt to establish whether exposure to RFR is associated with causes of death, or with life expectancies. By 1977, the records of about 20,000 deceased veterans whose military occupational titles indicated more probable exposure to RFR had been compared with those for an approximately equal number of less-exposed veterans. No quantitative exposure data were available. No differences between groups emerged in overall mortality rates or in the rates for about 20 specific categories of cause of death. However, death rates differed significantly for two categories: death rates from arteriosclerotic heart disease were lower and those from trauma were higher in the RFR-exposed group. The trauma category included military aircraft accidents, and a higher proportion of the exposed group had become fliers. It therefore appeared unreasonable to attribute the higher trauma death rate to greater previous RFR exposure. Overall death rates for both groups were lower than those for the general U.S. population of the same age.

A sample of 605 RFR workers at various U.S. military bases was examined by two ophthalmologists. The incidences of 3 kinds of damage to the lens of the eye were compared with those for a group of 493 age-matched persons with no known history of exposure to RFR. Although the usual age-related increase in incidence of changes in the lens was observed in both groups, no differences between groups were observed. No attempt at specifying the level of microwave exposure for the exposed group was made.

The incidences of fetal anomalies and fetal death rates reported in birth records for white children born in the vicinity of the Army Aviation Center at Fort Rucker, Alabama between 1969 and 1972 were evaluated in a series of three reports. Fort Rucker is of interest because of the concentration of radar units on or near the base. Taken together, these reports identify unusually high incidences of certain fetal anomalies and high fetal death rates in the two counties adjacent to Fort Rucker as compared with the corresponding statewide Alabama statistics, and at the Lyster General Hospital (Fort Rucker) as compared with other military and civilian hospitals. A high incidence of fetal death at the Eglin AFB Hospital is also reported. No further mention is made of the Eglin data in the remainder of the report. However, there was also evidence that these high rates for Fort Rucker could not be attributed specifically to the unquantified radar exposures at or near Fort Rucker on the basis of the birth record data: Coffee and Dale counties ranked only sixth and eighth for anomaly incidence among the 67 Alabama counties, Lyster Hospital's anomaly and fetal death rates were not significantly higher than several other comparable "non-radar" hospitals in Alabama and were in the range of values predicted from carefully controlled studies done in other states, there was no clustering of the residences of mothers bearing anomalous infants near radar sites, and there was significant time-clustering of anomalies reported at Lyster,

indicating a high anomaly-reporting rate for one or two specific physicians on the Lyster staff.

The report on the medical assessment of personnel assigned to the U.S. Embassy in Moscow from 1953-1976 was published in 1978. RFR beams of low intensity, ranging from 15 microwatts/cm$^2$ down to fractions of microwatts/cm$^2$ over daily periods of from 9 to 18 hours at frequencies from 2.5 to 4.0 GHz were directed at the Embassy. The authors compared medical examination records and health questionnaires for persons assigned to the Moscow Embassy and their dependents with those from comparable groups assigned to other East European embassies that have not been irradiated with microwaves. The authors of the study noted several limitations of the study (summarized in Section C.7.1, p. C-31), but were able to draw the conclusions that, with few exceptions, there were no differences in health status between the two groups on the basis of the information available to them and that they had found no convincing evidence that any adverse health effects among the Moscow embassy personnel were related to exposure to microwave radiation.

Male Polish radar workers were assigned to two groups based on whether they had been exposed for a period of years at an estimated power density greater or less than 200 microwatts/cm$^2$. The incidences of changes in the lens of the eye and several neurotic disturbances in the two groups were compared. No significant differences were found. The lack of a control group weakens the findings somewhat, but the two groups were apparently well-matched except for the intensity of exposure. The higher exposure group had 507 men, the other had 334.

Fifty-eight employees of Czechoslovakian television transmitter stations (48.5 to 230 MHz) with estimated exposures at 0 to 22 microwatts/cm$^2$ for an average of 7.2 years were subjected to a battery of medical evaluations, including electrocardiograms, chest x-rays, blood counts and blood chemistry, organ function tests, and psychologic tests. Although no comparable control group was evaluated, the only finding that was not within the normal range was a higher blood protein level. The significance of this single positive finding among this wide range of tests conducted is unclear, even to the author, who states "we do not have any explanation for this mean higher plasma protein level."

The following three recent reports from the USSR are representative of the literature on RFR from that country, which reports a wide variety of clinically measurable effects in personnel exposed to RFR. No similar studies have been carried out by Western investigators.

Sixteen kinds of symptoms were evaluated in a study comparing workers exposed to RFR at power densities ranging from less than a few tens up to a few thousands of microwatts/cm$^2$ with a nonex-

posed control group matched for age and type of work. Incidences of the symptoms were higher in the exposed groups than in the nonexposed group for all 16 kinds of symptoms. Fatigue, irritability, sleepiness, partial loss of memory, heart rate changes, blood pressure changes, and pain in the region of the heart were among the symptoms evaluated. The report concludes that unless persons suffering from "microwave sickness" are removed from the RFR exposure area, the symptoms will continue.

Another survey of Soviet workers occupationally exposed to "non-thermal" intensities of RFR at 40-200 MHz for periods of 1 to 9 years indicated that symptoms of nervous system disorder, cardiovascular changes, blood cholesterol elevation and gastrointestinal disorders were more common in the workers exposed to RFR than in controls. No statistical methods or descriptions of the control group characteristics were included in the report.

A third report was an assessment of workers exposed to RFR at 1-150 MHz, 300-800 MHz, or 3-30 GHz, with power densities, where specified, from 100-3,300 microwatts/cm$^2$, depending on their particular occupations. Changes were reported in brain wave patterns and in blood sugar, proteins, and cholesterol levels, as compared with those in administrative (nonexposed) personnel. The 300-800 MHz range includes the PAVE PAWS frequencies, but no estimates of power density were given in the report.

The U.S. studies as well as the Polish and Czechoslovakian studies provide no evidence of detrimental effects on populations exposed to microwave radiation. The USSR studies conclude that exposure to RFR does result in various symptoms, but the power densities described in the USSR studies are much higher than those predicted for PAVE PAWS. In addition, the manner of presentation of the USSR findings is such that the findings are largely not amenable to critical evaluation. Hence, the significance to be attached to the USSR findings is based on the degree to which the conclusions are accepted at face value. We conclude that, taking all ten of the studies together, the epidemiologic information does not provide evidence that the PAVE PAWS emissions will constitute a hazard to the population in the vicinity of the facility. ++

3.1.2.1.7.2 Mutagenic and Cytogenetic Effects. Several published reports indicate that mutations have been found in biological test systems exposed to RFR. Other studies find no evidence of mutations as a result of RFR exposure. Two questions arise under these circumstances: Is the statement that exposure to RFR produces mutations a valid conclusion from the data? If so, do the mutations result from effects of the radiation on deoxyribonucleic acid (DNA), or do they arise as secondary effects resulting from heating, drying, or other thermal effects of the radiation?

Studies of mutagenic effect of RFR in fruit flies and bacteria (both standard test systems for mutagenesis) had negative results.

No mutations were found. Yet a study of so-called dominant lethal effects of RFR in mice (another standard test system for mutagenesis) gave marginal positive evidence of mutation, and a similar type of study in plants also had positive results. The study with mice has two serious flaws. First, two studies were performed by the same investigator at approximately the same time in the same type of mice, and for the two studies there was a large difference in the incidence of naturally occurring mutations. Exposure produced very small increases in the incidence of mutations, and if the value given for the natural incidence is at all questionable, the conclusion that the radiation caused lethal mutations in the mice is probably invalid. The second flaw is that the mice were anesthetized during exposure, and anesthesia in mice blocks the normal mechanisms for control of body temperature. Hence, the effective dose of RFR in terms of heating may have been rather higher than the reported dose. Thus, any true mutations produced by the radiation might have resulted from overheating the testes of the mice. A more recent study in rats failed to find evidence of dominant lethal mutation. +

The study in plants found evidence of lethal mutations in the second generation of seeds derived from pollen exposed to RFR. However, the degree of mutagenic effects was not a linear function of the time of exposure, as one might expect if it was a direct effect of the RFR on the genetic material. Four hours of exposure caused no mutations, 12 hours increased the incidence of mutations to 2 to 3 times the natural rate, and 44 hours increased the incidence to 3 or 4 times the natural rate. The results indicate very strongly that the mutations were caused not by the action of the RFR on the genetic material, but by some secondary effect on the pollen, such as heating or drying of the pollen.

Other studies have been conducted on effects of RFR on the structure of chromosomes in cells. Such effects are generally considered to indicate the possibility of genetic effects, but do not constitute absolute proof of genetic effects. Four RFR studies were reviewed for this document. One claimed to find chromosome aberrations in cells after exposure, but in fact did not; two of the studies were conducted at such high power density levels that heating of the culture was virtually certain, although no temperature measurements were reported; and the fourth study reported a rise in the temperature of the culture.

All of the studies on mutagenic effects of RFR exposure reviewed here indicate that it is likely that the effects that have been found are related to heating. There is no evidence that power density levels incapable of producing significant heat, such as those outside the PAVE PAWS exclusion area, are likely to cause mutagenic effects. ++

3.1.2.1.7.3 Studies on Teratogenesis and Developmental Abnormalities. Teratogenesis is the production of malformed infants by processes affecting their development *in utero* (i.e., in the womb). The term developmental abnormalities, as used here, refers to processes affecting the development of infants after birth. Teratogenic and developmental abnormalities occur naturally at a low rate in most animal species, and relatively little is known about their cause. In a few cases, however, specific agents have been shown to cause significant teratogenic effects, and hence the possibility of teratogenic effects from RFR is an appropriate matter of public concern.

Teratologic studies with RFR have used a variety of animal models. One set of studies was performed on pupae of the darkling beetle, *Tenebrio molitor*. Several reports from two different laboratories stated that relatively low levels of RFR would produce developmental abnormalities in the pupae. Exact doses, referable to RFR fields in the environment, were not stated in these reports. However, a follow-up study in one of the laboratories reported that the number of developmental anomalies depended on such factors as the source of the larvae and the diet fed to them before they entered the pupal stage. This study reported also that under worst conditions, production of developmental anomalies required exposure for 2 hours at a mean SAR of 54 milliwatts/g (approximately eqivalent to 192,000 microwatts/cm$^2$) -- a substantial dose. Under the circumstances, there is no evidence from the beetle studies that RFR at the levels anticipated from PAVE PAWS is teratogenic.

Teratogenic studies have also been carried out on the incubating eggs of birds. A carefully performed series of studies was conducted on the eggs of Japanese quail, which were exposed continuously at 5,000 microwatts/cm$^2$ for the first 12 days of incubation. Incubator temperatures were controlled so that exposed and nonexposed eggs were at substantially the same temperature at all times. No gross deformities were seen in the exposed chicks at hatching, and the only differences observed between control and exposed birds were slight differences in hemoglobin (contained in red blood cells and important in oxygen transport) and monocyte (a form of white blood cell) counts at 36 hours after hatching, and slight differences in the weights of the male birds for the first 5 weeks of life.

Other RFR studies with chicken eggs have reported effects on cranial development at an average power density of 3,300 microwatts/ cm$^2$ and other teratogenic effects at 20,000 microwatts/cm$^2$. Neither study reported details on control of temperature inside the eggs. In the first study the authors claimed that the results might indicate an "adverse athermal effect" because the incubator temperatures were below the optimum for incubation. However, the direction of the effects produced depended on the temperature of the incubator, which suggests a thermal effect of the RFR. In the second study, the

whole exposure session involved a heat input of at least 42 cal/g, which would cause a significant temperature rise under the exposure circumstances, so heat is extremely likely to have caused the teratogenic effects that were reported.

Several studies have been performed to test for teratologic effects of RFR in mice. In a study done on the 8th day of gestation, RFR doses in the range of 3 to 8 cal/g (approximately equivalent to 123,000 microwatts/cm$^2$ for 2 to 5 min) produced a number of abnormalities, including exencephaly, a disorder in which the skull does not close and the brain is exposed ("brain hernia"). No abnormalities were reported at doses less than 3 cal/g -- which is about 25 to 30% of the lethal dose in these animals. In another study, done on various days of pregnancy, several different teratogenic effects were found after exposure to RFR. The types of effects found depended on the day of pregnancy on which the animals were exposed and were not different from effects produced by known teratogenic agents. Radiation dose levels were not specified, but the report stated that no malformations were produced in the offspring unless the pregnant animal's rectal temperature rose by at least 2 deg C (3.6 deg F). In a third study, mice were exposed to RFR at a dose of 5.5 cal/g (approximately 135,000 microwatts/cm$^2$ for 10 min) on the 11th through the 14th days of pregnancy; no teratogenic abnormalities were produced. In a fourth study, radiation doses estimated at 2.5 to 20 joules per gram (3,400-28,000 microwatts/cm$^2$ for 100 min) were given to mice daily during pregnancy. The authors reported finding 27 anomalies among 3,362 live fetuses exposed to RFR, as compared with 12 among 3,528 controls. Because of the small number of results for each individual anomaly, inconsistencies in dose response, and irregularities in the distribution of findings among groups, the authors were unable to accept the results as clearly due to RFR exposure.

Several studies have been conducted in rats and monkeys to determine whether RFR exposure during pregnancy will have any effect on the development of neurological function or normal behavior patterns in the offspring. Exposure at low levels (100-10,000 microwatts/cm$^2$) had no effect on these functions.

In summary, all of the studies showing significantly demonstrable teratogenic effects in mice following exposure to RFR have involved power density levels that are capable of producing a significant heat load to the animals. The results indicate in general that a threshold of heat induction or temperature increase must be exceeded before teratogenic effects are produced. Because the normal human metabolic rate is of the order of 1,000 to 2,000 microwatts/g, even the calculated power density of 160 microwatts/cm$^2$ at one small portion of the PAVE PAWS exclusion fence with the growth option will not have any significant effect on body temperature to cause teratogenic effects. Human infants *in utero* could not be affected by the maximum environmental level of RFR from PAVE PAWS.

3.1.2.1.7.4 Ocular Effects. The fear that RFR can cause cataracts is a recurring theme in newspapers and other popular media. Indeed, based on many investigations with animals by various researchers during the past 30 years, it is undoubtedly true that if a person's eyes were exposed to intensities high enough to elevate the temperature of the lens of the eye by about 5 deg C (9 deg F) or more, the lens would quickly suffer damage. The power density necessary for such a temperature rise in the lens is about 500,000 microwatts/cm$^2$ at 2.45 GHz and is higher at lower frequencies (e.g., at 450 MHz). Also, the lens is the most vulnerable region of the eye because other regions have more effective heat-removal means such as greater blood circulation, evidenced by much smaller temperature elevations in these regions than in the lens at the same incident power density. Therefore, the basic controversy regarding ocular effects is centered on whether exposure to much lower intensities (i.e., to power-density levels that would produce much smaller lens-temperature elevations) for long periods of time, either continuously or intermittently, can cause eye damage.

Implicit in this controversy is whether effects (if any) of long-term, low-level exposure in the eye are cumulative, as is the case for, say, the continual ingestion of certain toxic substances in minute amounts, each of which is well below rapid-toxicity levels.

3.1.2.1.7.4.1 Animals. Investigations with animals indicate that progressively lower intensities than about 500,000 microwatts/cm$^2$ require increasingly longer exposure durations to produce eye damage. For example, exposure of the eyes of a rabbit for 1-2 minutes at about 500,000 microwatts/cm$^2$ produces cataracts, whereas about 20 minutes is necessary at about 200,000 microwatts/cm$^2$. Also, at slightly lower power densities, the exposure time for cataracts increases greatly. In fact, exposure for 100 minutes at approximately 100,000 microwatts/cm$^2$ failed to produce cataracts. (Longer exposures were not used in this investigation.) Curves of power density versus exposure duration based on such experimental data show that the power density asymptotically approaches a constant power density or threshold value of about 150,000 microwatts/cm$^2$ for cataract generation, implying that exposure of power densities below the threshold will not cause cataracts no matter how long the exposure duration. Moreover, there is no experimental evidence of delayed onset of cataracts (latency), i.e., their occurrence long after exposure is terminated. The existence of a cataractogenesis threshold of about the same value has been reported by a number of independent investigators.

Several investigators compared the ocular effects of pulsed RFR at average power densities well above 100,000 microwatts/cm$^2$ with the effects of continuous-wave (CW) RFR at equivalent power densities and could not detect any differences. Also, in a very

recent study, rabbits were exposed to pulsed RFR at a pulse power density of 1,500,000 microwatts/cm$^2$ at a duty cycle of 0.001, equivalent to an average power density of 1,500 microwatts/cm$^2$, for 2 hours per day over a period of 3 months, with no evidence of eye damage.

All of the foregoing experiments with animals indicate that cataract generation by exposure to RFR is essentially a gross thermal effect. Indeed, in several investigations, cooling of the eye while exposing it to power densities normally high enough to damage the lens failed to cause damage.

3.1.2.1.7.4.2 Humans. With regard to ocular damage in humans, ophthalmologist Dr. M. M. Zaret contends that there are RFR-induced cataracts in a number of his patients, who presumably were occupationally exposed on military bases, in an industrial factory that manufactures and tests military radar or communications equipment, or other analogous circumstances. It is conceivable that patients of Dr. Zaret exhibiting significant vision impairment may have been exposed to power densities sufficient to cause thermal damage, but we do not believe that such vision impairment was due to prolonged exposure to power densities well below threshold. We base our opinion on the previously discussed results on animals and on studies of personnel at a number of military bases for possible cataracts due to RFR exposure, conducted by a group of ophthalmologists led by Dr. B. Appleton over a period of 5 years. In these studies, military personnel identified as having been occupationally exposed to RFR were matched in age and sex with other military personnel not occupationally exposed at the same bases. The eyes of personnel from both groups were examined by ophthalmologists for three signs, taken for purposes of the survey as diagnostic precursors of cataracts: opacities, vacuoles, and posterior subcapsular iridescence. The examination procedure used ensured that the examining ophthalmologists did not know to which group (exposed or control) each person belonged. Statistical analyses of the results indicated that although the numbers of persons exhibiting these diagnostic signs increased with age, differences between exposed and control groups were not statistically significant.

A common feature in both Dr. Zaret's and Dr. Appleton's work is the lack of adequate information regarding previous exposure histories and conditions (e.g., power densities, durations, frequencies). However, in Dr. Appleton's work, it is likely that most of the people in the control groups received very little, if any, exposure and most of the people in the exposed groups did. Therefore, the finding of no statistically significant differences between exposed and control populations should be accorded greater weight than claims that do not offer analogous comparisons.

In summary, based on the experimental results with animals that indicate the existence of a threshold power density of

approximately 150,000 microwatts/cm$^2$ and the finding of no statistically significant differences between exposed and control groups of humans on military bases, there is no evidence that prolonged exposure of humans to the RFR from PAVE PAWS at the power densities existing outside the exclusion area is likely to cause eye damage.

3.1.2.1.7.5 Nervous System Studies. Several types of studies have been conducted on effects of RFR on the nervous system of animals. These studies are considered particularly important in the USSR, where RFR is believed to stimulate the nervous system directly and thereby cause a variety of physiological effects. Scientists in the United States tend to doubt that RFR interacts directly with the nervous system except, possibly, under special circumstances (to be discussed later in this section), and they consider most RFR effects to result from other sources.

In summary, three of the effects considered in this section (RFR hearing, blood-brain barrier permeability, and brain histopathology) are most probably thermal in nature and involve RFR power density levels considerably greater than those that would be encountered in the neighborhood of PAVE PAWS outside the exclusion area. Another reported effect (that of changes in brainwave pattern) is probably not a real effect of RFR but an artifact produced by experimental procedure. Also discussed is the RFR-induced alteration of calcium exchange between brain tissue samples and the fluid bathing them. The general evidence provides no indication that the RFR outside the PAVE PAWS exclusion area will have any adverse effect on the nervous system or neurophysiological function of humans.

3.1.2.1.7.5.1 RFR-Hearing Effect. The phenomenon of RFR hearing has attracted widespread interest among scientists in the United States (also discussed in Section 3.1.2.1.6.1.2, p. 3-34). Much of the interest arises from theoretical implications of the process for study of the interaction of RFR with biological structures *in vivo* (i.e., studies on whole animals). Briefly, if an RFR beam is directed at the head of a human subject in the form of a relatively intense (300,000 microwatts/cm$^2$ or higher), short duration (about 20 microseconds) pulse, then that pulse can be heard by the subject as an audible "click." A number of theoretical and experimental studies have been conducted on the cause of the sound and the conditions under which it can be heard. The consensus of the results is that the sound arises from a thermally generated shock wave that is transmitted to the middle ear and then heard as a click. Persons with impaired hearing are unable to hear the click, and experimental animals in which the cochlea (the inner ear) has been destroyed will not exhibit brainstem-evoked responses. Because the hearing effect involves the intense, short-duration pulse, low average power density thresh-

olds calculated on the basis of a train of pulses spaced relatively far apart is not particularly meaningful. Continuous wave RFR has no effect on the brain until the average power density level is well above the threshold for thermal effects.

3.1.2.1.7.5.2 Calcium Efflux. Exposure of samples of neonatal chick brain tissue to RFR that has been amplitude-modulated at low frequency has been reported to increase the rate of exchange of calcium ion between the tissue and the fluid bathing it. This effect has been confirmed by independent studies in a second laboratory. Preliminary observations of the effect in the brains of awake, paralyzed cats have also been reported. The effect is scientifically interesting, in that it represents a rare instance where RFR may be producing a biological effect by processes other than thermal mechanisms. There are, however, several difficulties in the interpretation of the results with regard to human health and safety. First, the phenomenon is subtle. Second, the observations are highly variable and difficult to reproduce. Third, the circumstances of experimental methodology are such that the observations of changes of calcium exchange appear to apply to the surface region of the brain rather than to the brain as a whole. Finally, the phenomenon depends upon the amplitude modulation of the RFR in a narrow frequency band around 16 Hz and only occurs for a narrow range of average power densities -- a "window" -- between 100 and 1,000 microwatts/cm$^2$. Nevertheless, because this window is above the levels of general public exposure from PAVE PAWS, the occurrence of this effect in humans is unlikely.

3.1.2.1.7.5.3 Blood-Brain Barrier Effects. In most regions of the brain there is little or no movement of large molecules, e.g., proteins or polypeptides, from the blood into the surrounding tissue. The resistance to this movement is described as the "blood-brain barrier"; no visible physical structure is implied. Effects of RFR on the blood-brain barrier have been studied in several laboratories, using a variety of test systems. Two of the studies explicitly reported that increased permeability of the blood-brain barrier occurred only when the RFR produced a rise in brain temperature. In another study, the power density and duration of exposure of the RFR (10,000 microwatts/cm$^2$ for 2 to 8 hours) implied that very probably the temperature of local regions of the brain was raised. One study reported an increased permeability of the blood-brain barrier after exposure to RFR at 30 to 3,000 microwatts/cm$^2$, but the exposure system at the lower power densities required a particular schedule of pulsing. Two independent attempts to repeat this work gave negative results. One of the studies reported that apparent permeability of the blood-brain barrier existed in about 20% of the control animals, and that after exposure the incidence of permeability rose to about 50% of the exposed animals. The same study noted that the RFR-produced

permeability of the blood-brain barrier was a transient effect that disappeared within two hours of termination of the exposure. On the basis of the evidence available, it is unlikely that the RFR in the population centers around PAVE PAWS would have any detectable effect on the permeability of the blood-brain barrier. +

3.1.2.1.7.5.4 Histopathology of the CNS. Histopathological studies of the effects of RFR on the brain have been conducted both in the United States and in the USSR. Studies in the USSR have covered a wide range of frequencies, but the reporting of dosimetry and methods is inadequate in many instances. Exposure of animals (species not described) to their so-called decimeter waves (500 MHz to 1 GHz, no additional information on frequency) at 10,000 microwatts/cm$^2$ for 1 hr/day for 10 months resulted in various changes from normal appearance of nerve cells of the brain, as detected by delicate elective neurohistological methods (not otherwise specified). The authors reported that the power density did not raise body temperature, but the method of exposing the animals was such that the absorbed dose of radiation must have varied considerably among the animals. The reported changes in appearance were similar to those found in other experiments of a frankly thermal nature, and it is most probable that the reported effects in the chronic experiments were also of thermal origin.

Histopathological studies in the United States of the effects of RFR on the brain have been conducted on hamsters exposed to power density levels between 10,000 and 50,000 microwatts/cm$^2$ for periods of between 30 minutes and 24 hours. Chronic exposures have also been conducted at similar power density levels over a period of 22 days. Pathological changes in these studies were found only in the hypothalamus and subthalamus, two regions near the center and base of the brain. Reviewers of this study noted that the nature of RFR absorption inside the skull of such a small animal at the frequency used could lead to regions in the brain where the absorbed dose would be tens of times higher than that expected from the nominal power density. Rectal temperature measurements in the animals would not reflect such a condition. The observed pathological effects seem likely to have resulted from thermal processes.

3.1.2.1.7.5.5 EEG Studies. A number of studies have been attempted on the effect of RFR on EEG or other electrophysiological properties of the nervous system. These studies have encountered considerable technical difficulties. Where studies attempt to measure EEG changes during application of the RFR, the electrodes and leads used to pick up EEG signals will also pick up electrical transients from the fields, causing artifacts that render the recordings difficult to interpret. Where EEG studies are made after radiation exposure, the time consumed in placing and attaching the electrodes and the variability of placement of

the electrodes introduce additional problems of interpretation. To meet the latter difficulty, experiments have been conducted with indwelling electrodes. However, such indwelling electrodes will perturb the electric fields in their vicinity, and produce great enhancement of energy absorption, thereby creating still another artifact in the biological data. To meet these problems, specially designed indwelling electrodes of high-resistivity materials that do not cause field perturbation have been constructed and employed. Results obtained in experiments where either type of electrode (metallic, or high resistivity) are discussed below.

Two groups of researchers, using implanted metallic electrodes, reported changes in EEG patterns after acute or chronic exposure of rabbits to RFR. Another group, using implanted electrodes made of carbon instead of metal (an attempt to avoid the field distortion artifact) reported no significant differences in EEG between irradiated and control rabbits after 3 months of RFR exposure (1,500 microwatts/cm$^2$, 2 hr/day). Another study, using electrodes externally placed after exposure, rather than indwelling ones, reported no differences in EEG pattern between control and RFR-exposed monkeys at the end of a period of more than 12 months of exposure. Finally, a study of rats exposed to RFR before birth through age 92 days (indwelling electrodes again not used) showed no differences from control animals when both groups were tested at 140 days of age.

3.1.2.1.7.6 Effects on Behavior. A very large number of experimental studies have been conducted on the effects of RFR on animal behavior. The results of such studies are considered particularly important in the USSR, where they are often considered to be evidence for direct effects of RFR on the CNS. Scientists in the United States do not always agree that behavioral effects necessarily imply direct effects on the CNS. However, behavioral effects are very sensitive indicators of biological function, and hence receive appropriate attention on both sides of the Iron Curtain.

3.1.2.1.7.6.1 Radiation Avoidance Response. One type of behavioral study involves determining whether the subject animal can perceive or sense the radiation, and if so, whether it will avoid the radiation or treat it as a noxious stimulus. One series of studies in the United States found that if a rat were able to move freely in the exposure chamber, it would orient itself so as to minimize absorption of the radiation. Another experiment in the same series showed that when a mouse was able to turn off the RFR for a brief period (by interrupting a light beam), the mouse would do so regularly and repeatedly. In another experiment in the same series, the exposure to RFR was coupled with drinking sugar solution. When the rats were tested with more sugar solution 24 hours

later, they drank it quite readily, indicating that the sugar solution was not associated with an unpleasant experience. This experiment was a repetition of a classic study done over 15 years ago with ionizing radiation. In the ionizing radiation study, the rats associated the sweet solution with the radiation as an unpleasant experience, and refused to drink it again when tested later. The overall results in the current study with RFR suggest that the animals may avoid the radiation, but they do not perceive the radiation as a noxious stimulus or the source of unpleasant experience. The avoidance of the radiation itself may simply be an avoidance of the heat load generated by the radiation.

3.1.2.1.7.6.2 Acute Effects: Behavior Depression. In another type of behavioral study, a number of experimenters have shown that RFR can interfere with or suppress the performance of tasks by trained rats and monkeys. In acute studies a power density threshold had to be exceeded before the performance decrement occurred. The power density thresholds were 5,000 to 50,000 microwatts/cm$^2$, and the threshold seemed to depend somewhat on the complexity of the task and the level of discrimination required of the subject. The mechanism of the interference is not known, but one study of rats that were subjected to a swimming test after a very large RFR dose noted that the animals seemed to tire more quickly than unexposed controls.

3.1.2.1.7.6.3 Chronic Effects. Suppression of performance of tasks was also found when trained animals were exposed chronically to RFR. Power density levels varied; in one series of experiments, it was 1,000 to 10,000 microwatts/cm$^2$, clearly in the thermal range for these animals. In this experiment, the results were similar to those found in the acute exposure studies, and the author reported that the animals did not accommodate to the exposure during the experiment. In another experiment, rats were exposed to RFR at 10 or 50 microwatts/cm$^2$, 7 hours per day for 90 days. The author reported changes in the rate of learning an avoidance response and changes in the threshold for electric shock to the foot.

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3.1.2.1.7.6.4 Pulsed RFR Effects on Natural Behavior. Some +
studies have been conducted on the effect of RFR on the so-called "natural" behavior of animals. RFR exposure was found to inhibit exploratory behavior of rats placed in novel situations, to inhibit an aggressive response of rats to acute pain, and to disturb the motor coordination in a balancing test. Some of these effects were obtained at pulse power density levels from 50 to 700 +
microwatts/cm$^2$.

3.1.2.1.7.6.5 Summary of Behavioral Effects. It is difficult to relate most of the behavioral studies in animals to humans. Many studies on "natural" behavior involve tests that can be performed only once on a given animal; hence, no information is available on the question of whether the effect of the exposure is transient or not. In addition, all behavior studies are directly relevant to the nature of the species being studied, and the conclusions of a given study do not readily transfer to another species. The most general conclusion that can be drawn from the studies reviewed here is that the majority of the RFR effects on behavior involve power density levels that appear to be in the thermal range. Of the studies conducted at lower values, some are of questionable value and the others involve results that have no demonstrated relevance to humans. At the power density levels outside the PAVE PAWS exclusion fence, these studies provide no evidence of adverse effects on human behavior.

3.1.2.1.7.7 Endocrinological Effects. Endocrinological effects of RFR fall into four classes: direct stimulatory (heating) effects on the organ itself, responses to whole-body heat load, responses to stress, and effects on the male reproductive system.

Direct stimulatory effects were found during local exposure of the thyroid glands of dogs. In response to the radiation, the glands increased their output of thyroxine (a hormone controlling metabolic rate in other cells in the animal) by a factor between 2 and 10. However, the effect occurred only at large power density levels, more than 70,000 microwatts/cm$^2$, and was accompanied by a significant increase in the temperature of the gland. If the temperature of the gland did not increase, no effect on output was observed. At the levels of RFR expected outside the PAVE PAWS exclusion area, no temperature rise in the thyroid gland would be possible; hence no change would occur in thyroxine output of the gland.

Typical responses to heat load were found in rats exposed to moderate power density levels over a period of several hours to several days. During the first 1-2 hours at levels of 10,000-20,000 microwatts/cm$^2$, the thyroxine level of the blood remained steady, but the level of thyrotropic hormone (a hormone that is secreted by the pituitary gland in the base of the brain and which control the production of thyroxine) began to decrease. After 4-8 hours, the thyroxine level of the blood also decreased. When the rats were exposed at slightly lower power density levels for 8 hours a day for 7-21 days, thyroxine and thyrotropic hormone levels of blood also decreased, and alpha-globulin (special blood protein) levels of blood plasma increased. The change in this protein was considered to be a secondary effect of the decreases in thyroid hormone levels.

The changes in thyroxine and thyrotropic hormone observed in these animals are predictable responses to additional heat loads. They did not differ from the expected effects of changing environmental loads in other ways (e.g., by changing the thermostat setting in the animal quarters). At the power density levels expected outside the PAVE PAWS exclusion area, heat loads will not be increased measurably. If temperature does not increase, there is no change in thyroid hormone release. + +

Typical stress responses were found in rats exposed to moderately high power densities of RFR, 20,000 to 50,000 microwatts/ $cm^2$. Responses were increases in corticosterone (a hormone secreted by the adrenal gland) and decreases in growth hormone (secreted by the pituitary gland) in the blood plasma. The stress response varied with power density level and duration of exposure and was associated with a rise in body temperature. Power density levels having only a marginal effect on body temperature produced no stress response. Stress response at the even lower power density levels of PAVE PAWS outside the exclusion fence is most improbable. (See Section 3.1.2.1.7.8.2, p. 3-54, for additional RFR-induced stress studies.)

Exposure of rats to RFR levels of 10,000 microwatts/$cm^2$ caused irregular and unexplained changes in the levels of luteinizing hormone and follicle-stimulating hormone in the pituitary glands. The effect was studied over a period of several weeks, and it did not appear to be progressive or cumulative. Another study (at an unspecified power level) showed that after 24 hours of exposure, the level of plasma testosterone in rats increased briefly. This effect could represent an effect of the RFR on the testes, which are notoriously sensitive to small temperature changes. Changes in the testes caused by heat or RFR are readily reversible, unless the heating is prolonged. Slightly reduced sperm counts have been found in men occupationally exposed to RFR, but their basic testicular function was not affected. At power density levels below 200 to 300 microwatts/$cm^2$, it is doubtful that the effect would occur. Thus, at the power density levels outside the PAVE PAWS exclusion area, effects on testicular function are doubtful. +

3.1.2.1.7.8 <u>Immunological Effects</u>. Effects of RFR on the immune system of animals have been studied extensively. Most of the investigations were motivated by questions of potential hazard to humans. RFR stimulation of the immune system might also be medically useful in treatment of human disease, and that provided an additional impetus for the other studies. The studies on the immune system reviewed here represent three general categories: <u>in vitro</u> studies (i.e., studies on isolated cells), <u>in vivo</u> studies involving acute RFR exposure, and <u>in vivo</u> studies involving chronic RFR exposure.

3.1.2.1.7.8.1 Iin-Vitro Studies. In vitro studies are all related to the question of whether RFR can stimulate human or animal lymphocytes (a type of white blood cell of key importance in the immune system) to transform into lymphoblasts (active forms of lymphocytes) and undergo cell division when they are cultured outside of the body. Normally, such cells are cultured in the presence of a mitogen (an agent, normally chemical) that stimulates blast transformation (i.e., lymphocyte to lymphoblast) and cell division. About 11 years ago, a report was published claiming that if the cells were cultured without a mitogen present and the cells were subsequently exposed to RFR, they would undergo blast transformation anyway. Since that time a number of studies have been conducted in an attempt to repeat this finding. Some of the results have been positive, some negative, and some equivocal. The consensus of the reports appears to be that RFR can stimulate the blast transformation of lymphocytes, but that the effect depends in a rather complex way on a rise in temperature of the culture medium.

3.1.2.1.7.8.2 In-Vivo Studies: Acute Exposures. Acute (i.e., short duration) in vivo studies, in which the RFR is administered one time over a period of five minutes to one hour, have all involved high power densities in animals, whose body temperature was virtually certain to rise. In general, the effects of acute RFR exposure on the immune system appear to be stimulatory. The number of circulating lymphocytes in the blood increases, as does the ability of the immune system to manufacture antibody to foreign substances. The number of cells involved in production of immune complement (a complicated series of interacting chemicals in the blood) also increases. The mechanism of those effects is not certain, but one study reported that the effects could be produced by injection of cortisone, suggesting that the effects on the immune system may be a secondary result of the stress induced in the animals by the RFR-produced heat or possibly by other stresses such as handling the animals. Other studies on RFR-induced stress are discussed in the section on hormonal effects. (Section 3.1.2.1.7.7, p. 3-52)

3.1.2.1.7.8.3 In-Vivo Studies: Chronic Exposure. Chronic RFR exposure of animals has resulted in mixed reports of effects on the immune system. Exposure of mice to 500 microwatts/cm$^2$ for 2 hr/day caused a general stimulation of the immune system that was observed after 6 weeks of exposure. When the exposure was continued to 12 weeks, the degree of stimulation was much smaller, suggesting that the immune system was returning to its normal state. Exposure of rats to 5,000 or 10,000 microwatts/cm$^2$ for 4 hr/day from pre-birth through 40 days of age also resulted in a stimulation of the immune system. Exposure of rabbits to 10,000 microwatts/cm$^2$ for 23 hr/day for 6 months resulted in a mild reduc- tion in the numbers of B-type lymphocytes (a subclass of lympho- cytes associated with antibody production) in the spleen.

Finally, studies in the USSR reported that exposure at 10 to 500 microwatts/cm$^2$ for 7 hr/day for 30 days resulted in a "downward trend" in numbers of T-type lymphocytes (a subclass associated with the thymus gland) in rats, but general stimulation of the immune system in guinea pigs.

Although temperatures are not reported in the chronic studies, exposures at 5,000 to 10,000 microwatts/cm$^2$ must be considered in the thermal range. Exposures at 500 microwatts/cm$^2$ may or may not involve local thermal effects, depending on animal size and frequency employed, and exposures at 50 microwatts/cm$^2$ or less are probably not thermal. The overall results suggest that RFR exposure initially causes a general stimulation of the immune system, but if the exposure continues, the stimulatory effect disappears, and may possibly be replaced by some degree of inhibition. As mentioned earlier, the mechanism of the stimulation is not known, but because many of the chronic studies were conducted at thermal or near-thermal power levels, the stimulation may have resulted from stress reactions induced by the RFR. Alternatively, the response may not have been related to exposure, but rather to other stresses such as handling, cold, etc. There is no evidence that RFR power densities outside the PAVE PAWS exclusion fence would be capable of inducing such reactions in humans.

3.1.2.1.7.8.4 Health and Disease. There is no evidence that PAVE PAWS-induced effects on the immune system are likely to prove hazardous for humans. Experimental studies have shown that RFR exposure does not increase the susceptibility of animals to death from infectious diseases, and some studies indicate that it may even have a protective effect against disease at high power density levels.

3.1.2.1.7.8.5 Conclusion. There is sufficient evidence to conclude that, under certain circumstances, exposure to RFR affects the immune system of mammals. For *in vitro* exposures, the effect appears to be a result of temperature change. For exposures of the intact animal, it is likely that the effect is of a general nature and is mediated via the pituitary and adrenal glands, as occurs for any stress situation. Less likely is the possibility of a direct effect on the cells of the immune system. Those studies reporting effects at low-level, longer-duration exposures (10s to 100s of microwatts/cm$^2$ for up to 30 days) in general have not been independently verified, but the effects cannot be excluded.

3.1.2.1.7.9 Biochemical and Physiological Effects. The literature on biochemical and physiological effects associated with RFR is extensive. Many of the reported effects are associated with other events (e.g., changes in hormonal levels or stress adaptation), some are questionable for various reasons, and others do

not have a clear medical significance. The brief review in this section addresses three principal questions: (1) Does RFR have any direct effect on respiration? (2) Does RFR have any direct effect on blood plasma composition or trace element content of the body? (3) Does RFR have any direct effect on deoxyribonucleic acid (DNA)?

Exposure of mice to RFR has been shown to cause a compensatory decrease in the animals' oxygen consumption. Exposure of germinating peas with RFR caused a decrease in oxygen consumption that was attributed to interference with the starch-glucose conversion system. The effect was associated with a rise in temperature in the peas. Exposure of cultured mammalian cells (Ehrlich ascites tumor cells from mice), subcellular units (mitochondria), and enzyme systems had no effect on the rate of oxygen consumption or metabolism. It can be concluded that if RFR had any effect at all on respiration rate, it is a secondary effect of heat absorption or temperature change.

RFR exposure has caused minor changes in the level of serum triglycerides, in the relative concentrations of the blood proteins, and in the amount and rate of various trace elements in the blood and tissues. The change in the level of serum triglycerides was found in mice exposed continuously over a span of 60 hours to a moderate level (3,000 to 4,000 microwatts/$cm^2$) of RFR. Although the effect could have resulted from direct stimulation by the RFR, it is more likely to be a secondary result of the not insignificant heat load. Changes in concentration of blood proteins were observed in the mice mentioned above and also in a group of workers at a television transmitting station in Czechoslovakia (see Section 3.1.2.1.7.1, p. 3-40). Although the changes observed in mice were probably secondary effects of the heat load, the changes in the Czech workers were probably unrelated to heat load. The findings thus may represent a possibly nonthermal biological effect of RFR. The report of this study stated that although the changes in protein concentration were statistically significant, the concentrations were still within the normal physiological range and the workers were in good health. In another study, changes in the concentration and rate of turnover of trace elements, notably copper, molybdenum, iron, and manganese, were reported in a study of rats exposed to RFR at power densities ranging from 10 to 1,000 microwatts/$cm^2$. The results are somewhat difficult to interpret, because tissue levels of these substances increased at high power densities but decreased at low power densities.

Overall, some of the changes in blood and tissue composition attributable to RFR are probably secondary effects of heat, but some may not be. The relationship of the changes to human health is uncertain. However, in one study workers who were probably exposed to higher power density levels than would be found in the vicinity of PAVE PAWS beyond the exclusion area were found to be in good health.

Studies of the effects of RFR on DNA *in vitro* have been conducted, but the reports do not present power density levels, so the results cannot be assessed quantitatively. An *in vivo* study of the effects of RFR on DNA in the testes of mice has also been reported. This work was part of the study of induction of dominant lethal mutations in mice that is discussed in the section on mutagenic and cytogenetic effects (Section 3.1.2.1.7.2, p. 3-41). After exposure of the testes to RFR at a substantial power density for 30 minutes under conditions that rendered the temperature regulatory system of the animal inoperative, the DNA in cells of the testes were found to have undergone some minor changes in physical properties. The author of the study attributed the changes to strand separation of the DNA molecules.

In summary, no evidence has been found that RFR affects oxidative metabolism or DNA structure except as a secondary result of the heat deposited by the RFR. RFR may possibly have effects on proteins of blood and trace elements in tissue at power densities below the level at which heat production would be significant. However, there is no evidence that such changes, if they occur, are harmful to human health.

3.1.2.1.7.10. Cellular Effects. A number of reported cellular effects of RFR have been discussed in other sections of this document. Effects of RFR on the chromosome structure of cells were discussed in the section on mutagenic and cytogenetic effects (Section 3.1.2.1.7.2, p. 3-41). Effects of RFR on lymphocytes and the induction of blast transformation in these cells were discussed in the section on immunological effects (Section 3.1.2.1.7.8, p. 3-53). Finally, effects of RFR on the respiratory metabolism of cells were discussed in the section on biochemical and physiological effects (Section 3.1.2.1.7.9, p. 3-55). Topics remaining to be discussed in this section are the technical problems of study of RFR effects in cells, effects of RFR on cell membrane permeability, and effects of RFR on cell viability and proliferative capacity. Studies reviewed in this section apply exclusively to *in vitro* work.

The principal technical problems in studying RFR effects on cells is that the studies are often conducted using conventional apparatus designed for cell studies -- flasks, dishes, holders, agitators, water baths, incubators and the like -- and various elements of the apparatus may distort the RF fields in such a way that the specific absorption rate of energy in the cell cultures may be severalfold higher or lower than field measurements would indicate. Some progress has been made in designing cell culture apparatus that will provide accurate, calibrated exposure to RF fields, but results of much of the formerly published work on cell and tissue cultures must be questioned with regard to the actual absorbed RFR dose in the cell culture media.

A number of earlier studies have reported that exposure of cells to RFR causes increased cell membrane permeability, leading to loss of vital cell contents. More recent studies, conducted with careful control of media temperature, have found no effects of RFR on cell membrane permeability other than those attributable to temperature rise.

Studies of effect of RFR on cell viability have been conducted on tumor cells and bacterial cells, using apparatus designed to avoid problems of RFR field distortion and also to keep the media temperature constant. Effects on tumor cell viability were evaluated by measuring the latency period for tumor development in animals following injection of the exposed cells. RFR fields approximately equivalent to 60,000 or 250,000 microwatts/cm$^2$ for 20 minutes had no effect on the viability of the tumor cells when constant temperature was maintained. Effects on bacterial cell viability were evaluated by measurement of cell plating efficiency. In addition, molecular structure of cell contents was determined by infrared spectroscopy. RFR exposure at power densities of 250,000 microwatts/cm$^2$ for 10 hours had no effect on either cell viability or molecular structure when constant temperature was maintained. +

In summary, many of the reported effects of RFR on cells _in vitro_ are questionable because of uncertainties in the actual absorbed doses in the culture media. This reservation applies not only to studies reported in this section, but also to the cytogenetic, immunological, and biochemical studies reported elsewhere. All of the studies on cultured cells have employed power density levels ranging from 100 to 2,000 times the levels expected outside the PAVE PAWS exclusion area, many of the results have been negative, and most of the rest can be clearly traced to temperature changes. There is no evidence from these cellular effects (or lack of effects) of RFR to imply any potential hazard to human health from the RFR associated with PAVE PAWS outside the exclusion area.

+

3.1.2.1.7.11 _Other Effects_. Two major health effects that have been attributed to RFR are increases in cancer and cardiovascular disease. Examination of reports of these effects shows that the evidence does not support the claims. +

3.1.2.1.7.11.1 _Cancer Studies_. Claims for cancer induction have been found in only three scientific reports. In the first, the author claimed that the incidence of cancer in a district of Finland increased after construction of radar facilities across the border in the USSR. The statement was not supported by either data or references. The second was a publication suggesting that the incidence of leukemia in mice rose after chronic, long-term RFR exposure. Details of pathological diagnoses were not given. +

When the data were analyzed by appropriate statistical methods, no difference between mice exposed to the RFR and unexposed controls was found. The third report cited the first two and then uncritically reviewed reports of cytogenetic and mutagenic effects from RFR. Although such effects have been associated at times with chemical carcinogens, the review in the document failed to consider the likelihood that these are secondary effects caused by heat rather than direct effects of exposure. A more extensive discussion of this latter question is given in the section on mutagenic and cytogenetic effects (Section 3.1.2.1.7.2, p. 3-41).

3.1.2.1.7.11.2 <u>Cardiovascular Studies</u>. The report that claimed an increase in cancer in Finland also stated that the incidence of cardiovascular disease increased in the same region during the same period. Again, the statement was not supported with data or references.

Various studies in the United States and the USSR have claimed or denied that RFR has increased or decreased the rate of heartbeat in humans and experimental animals. Heart rate may change temporarily for a variety of reasons, and in the absence of a consistent trend based on interference with known mechanisms of cardiac control, claims for effects of RFR on heart rate are of dubious medical significance. Reliable reports of persistent hypertension or arteriosclerosis associated with exposure to RFR have not been found.

3.1.2.1.7.11.3 <u>General Health; Chronic Studies</u>. A number of studies have been conducted on animals (usually mice or rats) that were chronically or repeatedly exposed to RFR for a significant period of time. Indicators of general health commonly used in such studies -- body weight, food consumption, blood-cell counts, and life span -- have shown that animals can be exposed to substantial power density levels of RFR daily without evidence of gross harm.

3.1.2.1.7.11.4 <u>Summary</u>. In summary, there is no evidence that cumulative harmful effects have resulted from chronic exposure to RFR, other than specific effects caused by overheating of tissues at high power densities. While scattered references point to effects of RFR on cardiac function, no evidence shows that serious cardiovascular disease has been caused by RFR exposure. Higher incidences of cancer were not found in animals chronically exposed to RFR, nor were they found in epidemiological surveys of people occupationally exposed to RFR. Furthermore, a review of other physiological effects of RFR reveals no evidence that RFR exposure at the ground level power densities calculated for PAVE PAWS are likely to promote cancer. Overall, there is no evidence to indicate that RFR at power densities in the range of those of PAVE PAWS outside the exclusion area will be harmful to humans.

3.1.2.1.8 Unresolved Issues. The potential biological effects of RFR from the PAVE PAWS facility have been assessed from existing studies in the 10 MHz to 18 GHz range. On the basis of these studies, with recognition that the negative findings reported in some studies may have been obtained because the investigations were poorly conducted, there is no evidence that general population exposure to the RFR from PAVE PAWS will be hazardous to human health. However, there are certain gaps in the knowledge of biological effects of RFR which the present data do not adequately cover. These gaps may be identified as follows:

a) Lack of sufficient experimental data and mathematical models to extrapolate studies done in animals to determine precisely the biological effects expected in humans. Moreover, most animal research is usually not done where continuous exposure occurs for times on the order of an animal's lifetime. These deficiencies apply both to the question of experiments done at different RFR frequencies and to differences in biological response among various species.

b) A lack of prospective epidemiological studies of effects of RFR on humans exposed to RFR. The present epidemiological studies, while extensive and reasonably well-done, are all retrospective in nature, and subject to certain inherent defects of method.

Because of the low levels of general population exposure from PAVE PAWS, the ability to assess whether the RFR from the radar will be potentially hazardous to humans is not affected by the existence of these gaps.

3.1.2.1.9 PAVE PAWS and Safety to Human Populations. In the previous subsections of Section 3.1.2.1 (beginning on p. 3-18), current state of knowledge regarding the biological effects of RFR was examined on a topic-by-topic basis by reviewing and analyzing representative articles relevant to PAVE PAWS from the large body of scientific literature published in this field. Discussions were also presented on related topics such as: background information on other RFR-emitting devices and equipment in the United States; problems of risk assessment, with regard to the scientific, philosophical, and range of legal applicability of such standards; mechanisms of interaction of RFR with biological entities, involving definitions of "thermal" and "nonthermal" and distinctions between interactions of CW and pulsed RFR; uncertainties in retrospective epidemiological studies; and the basic problems of assessing possible hazards to humans of any environmental agent by extrapolating results of experimental research performed on animals. The conclusions regarding whether the evidence indicates that operation of PAVE PAWS constitutes a possible hazard to humans and the basis for those conclusions are summarized below, with cognizance of the topics mentioned above.

The preponderance of U.S. experiments with animals that yielded recognizable and repeatable effects due to RFR were performed at incident average power densities of more than about 2,000 microwatts/$cm^2$. Such effects are thermal, in the sense that enough energy is absorbed as widely distributed heat that increases the whole-body temperature or as internally localized heat that is biologically significant, even with natural heat-exchange and thermoregulatory mechanisms operating. The existence of threshold average power densities for such effects has been shown or postulated. Exposure to RFR at average power densities exceeding the threshold for a specific effect for durations of a few minutes to a few hours (depending on the value) can cause irreversible tissue alterations, whereas for indefinitely long or chronic exposures at values well below the threshold, the heat produced is not accumulated because its rate of production is readily compensated for by heat-exchange processes or thermoregulation. Most investigations involving chronic exposures of mammals yielded either no effects or reversible, non-cumulative behavioral or physiological effects for average power densities exceeding 2,000 microwatts/$cm^2$. Also, researchers who used pulsed and CW RFR at the same average power densities and otherwise similar conditions generally found no differences in such thermal effects for the two classes of RFR. In the few cases where irreversible adverse effects of exposure were found, such effects were absent for average power densities below 2,000 microwatts/$cm^2$. Therefore, it is unlikely that exposure of humans to the average power densities from PAVE PAWS anywhere along the exclusion fence (calculated to be less than 90 microwatts/$cm^2$ for the basic system and less than 160 microwatts/$cm^2$ for the growth system) or anywhere for the general public (calculated to be less than 1 microwatt/$cm^2$ for both systems; measured at less than 0.1 microwatt/$cm^2$ for the basic system) would cause such thermal effects. + ++

Few experiments show biological effects of RFR at incident average power densities less than 2,000 microwatts/$cm^2$. Such effects are often grouped under the label "nonthermal," to distinguish them from those considered above. However, such usage of "nonthermal" is confusing and imprecise because the interaction mechanisms involved in each such effect differ considerably from those for the other effects and clear distinctions between "thermal" and "nonthermal" based on precise scientific definitions of these terms are difficult to discern in the interactions. Because the RFR from PAVE PAWS is pulsed, the RFR-auditory and calcium-efflux phenomena are relevant and are considered below. ++

The existence of the RFR-auditory phenomenon, i.e., perception of short pulses of RFR individually as audible clicks, is well established experimentally. For perception of an individual pulse by a human, the pulse duration must be about 10 microseconds or longer and the pulse power density must exceed a threshold value of about 300,000 microwatts/$cm^2$. Most of the experimental ++

results with animals indicate that pulses are perceived as actual sound by the auditory apparatus rather than because of direct RFR-stimulation of the auditory nerves or the brain. The effect is well explained by absorption of energy from a pulse arriving at an interface between tissues of widely different properties in the head; the energy is converted to heat at the interface, thereby causing sudden thermoelastic expansion and generation of sound waves that propagate to the auditory apparatus. Because the phenomenon can occur with a single pulse, the average power density is not a relevant parameter. Rather, the characteristics of each pulse are of importance. This phenomenon is not of concern relative to PAVE PAWS because the maximum pulse power densities at the exclusion fence (1,200 microwatts/cm$^2$ for the basic system and 2,400 microwatts/cm$^2$ for the growth system) are several orders of magnitude lower than the threshold pulse power density for human perception.

Calcium efflux has been reported for chick brains exposed to 147 MHz RFR modulated at 9, 11, 16, and 20 Hz, with the maximum effect at 16 Hz. Similar results were reported for 450 MHz RFR modulated at 16 Hz. The effect was absent for unmodulated 147 MHz or 450 MHz RFR. The existence of a power-density "window" was also reported. Specifically, with 450 MHz modulated at 16 Hz, the effect was detected for incident average power densities between 100 and 1,000 microwatts/cm$^2$ but not for values below or above this range. Preliminary results of calcium efflux from the cerebral cortex of the paralyzed, awake cat exposed to 16 Hz modulated 450 MHz RFR at an incident average power density of 375 microwatts/cm$^2$ were reported in 1977. The highest calculated value of average power density for the basic PAVE PAWS system is 90 microwatts/cm$^2$ (at the 250-ft location along one radial arm of the exclusion fence), a value that is smaller than both the lower limit of the power-density window for the chick-brain results and the value for the cat-brain results. For the growth system, the calculated average power density exceeds 100 microwatts/cm$^2$ only for 75 ft along the same radial arm of the exclusion fence, with a maximum of 160 microwatts/cm$^2$. This value is within the power-density window for the chick-brain results but is less than the value for the cat-brain results. Interpretations of these calcium-efflux results in terms of possible effects on humans are conjectural, because the degree of uncertainty in extrapolating positive quantitative results with laboratory animals to humans is often difficult to assess. Moreover, measurements on the basic system indicate actual power density values are less than the calculated values. ++

The relatively few retrospective epidemiological studies done in the United States and USSR are not considered evidence that the PAVE PAWS emissions are likely to constitute a hazard to the population. +

In summary there is no reliable evidence to support the conclusion that any hazard will result from either short-term or ++

long-term exposure of people to the RFR from PAVE PAWS outside the exclusion fence for either the basic or growth system.

3.1.2.1.10 Other Viewpoints. Some of the general concerns ++ expressed following review of the Draft Environmental Impact Statement are: First, there are insufficient data upon which to base an assessment of potential hazard to human health; second, research on the effects of long-term, low-level exposures is only in its infancy; third, little is currently known about the details of mechanisms of interaction of RFR with biological tissues, with the consequence that potentially hazardous effects that may occur have not been more precisely targeted for study; fourth, there are specific studies in the literature that report effects at average power densities less than 100 microwatts/cm$^2$; fifth, even though some studies report negative findings (i.e., no effects as a result of RFR exposure), such negative findings can possibly be attributed to faulty experimental design or procedures; sixth, epidemiological studies from the Soviet Union have reported various symptoms in persons exposed for many years to RFR at levels in the range from tens to hundreds of microwatts/cm$^2$ -- symptoms that when taken together are called the "microwave radiation syndrome" -- but that such symptoms are not recognized in Western epidemiology studies; seventh, although we know a lot more today than we did 10 years ago, we will know even more 10 years from now and it is therefore likely that with this additional knowledge will come recognition of new, hazardous effects of long-term, low-level exposure to RFR; eighth, safe power thresholds for RFR exposure of the general population have not been established, and, further, safety standards vary from country to country; and ninth, there has been insufficient research on possible alterations of genetic material and carcinogenic effects of long-term, low-level exposure to RFR.

Documentary evidence that has been presented by commenters as reasons for these concerns include: The studies by Bawin and Adey on calcium efflux changes; the studies by Frey on blood-brain barrier permeability changes and modifications of behavior, the studies by Shandala on changes in the immune system; the studies by Oscar on changes in permeability of the blood-brain barrier to certain radiotracer-labelled molecules. Many of the above references have been discussed in Appendix C.

We see no evidence that the low levels of general public exposure to PAVE PAWS RFR are hazardous. We are supported in this conclusion by the study recently completed by the National Academy of Sciences.

### 3.1.2.2 Plants and Animals

Significant effects on plants or animals are not expected to result from the operation of PAVE PAWS, either from the basic or growth-option systems. Temporary effects may occur in the near-field, for example, the temporary repelling or attracting of species that are sensitive to noise and other human disturbances associated with the radar operation. It is unlikely that any of these potential effects would substantially alter the local or regional ecosystems.

The quantitative data presented below are based on the basic system; however, the power densities calculated for the growth option system do not differ enough to substantially alter any of the qualitative analysis.

#### 3.1.2.2.1 Radiofrequency Radiation (RFR)

##### 3.1.2.2.1.1 Main Beam Exposure

At its lowest, the PAVE PAWS main beam is pointed at 3 degrees above the horizontal. Thus, the main beam is always directed above the plants and the fauna which inhabit them. Consequently, the biota that could be potentially affected by the main beam are airborne fauna, e.g. birds in flight and possibly airborne bats and high-flying insects.

Of special ecological interest are the migrating birds which might be affected, since Cape Cod is located along a major route of the Atlantic Flyway (see Section 1.2.1.1.1.2, p. 1-10). Nisbet (1963) has measured the altitude of migratory nocturnal flights over Cape Cod and found that most of the birds are at altitudes between 1,500 feet and 2,500 feet, and that 90% of the migrants are below 5,000 feet. Daytime migrations are expected to be somewhat lower (Bruderer and Steidinger, 1972). Therefore, most of the migratory birds will not be exposed to any main beam radiation from PAVE PAWS at distances greater than 12 miles from the radar, and 90% of the migratory birds will be below the beam at distances greater than 25 miles from PAVE PAWS. In any case, of greater ecological significance are the low power densities from the main beam. The average RFR power density from the main beam only exceeds 500 microwatts/cm$^2$ within about 1,000 ft from the radar.

As explained in Section 3.1.2.1, p. 3-17, the biological effects literature suggests that biological effects, not necessarily hazardous, are possible at 100 microwatts/$cm^2$ and upward. + Thus, the only potential area of concern due to near and transition field exposure consists of those few airborne organisms flying between about 300 ft and 400 ft MSL in the 240 deg span of surveillance, and only 1,000 ft and closer to the radar. The maximum length of exposure would be but a few minutes while the airborne organisms traverse this area. Airborne fauna directly in front of one face of the radar in the middle of the beam could be exposed to as much as 140,000 microwatts/$cm^2$ for brief periods of time (while the other face is limited to 60,000 microwatts/$cm^2$). There are no endangered or threatened flying animals in the area, and the few individuals and the extremely short duration of time the local airborne fauna would spend traversing in even these RFR fields indicates that adverse ecological effects would not result from their brief exposure to main beam radiations.

Minor localized effects may result in the near and transition field volume specified above. The radiation from PAVE PAWS might tend to cause birds to avoid the radar, and thus help eliminate the possibility of birds striking it (see Tanner and Romero-Sierra, 1969). On the other hand, birds might learn to seek out the radiation for warmth during cold weather (Gandhi et al., 1978). Regardless, any potential thermal effects from PAVE PAWS would be of very short duration, as well as being very localized.

"Nonthermal" effects on birds from low level RFR have been claimed by a few researchers (Tanner, 1966 and Tanner et al., 1967), but the methodology used in these experiments has been questioned (Krupp, 1976; Eastwood, 1967). Temperature measurements of the experimental subjects were not made, and the effects may have been thermal. Irrespective of whether the effects were thermal or nonthermal, the experimental arrangements (caged birds in highly restricted areas with horn antenna mounted on the cages) bear little relationship to the habitats in which a bird normally operates. Tanner and Romero-Sierra (1974) themselves have concluded that external environmental parameters such as temperature, humidity, and atmospheric pressure, as well as internal factors of the experimental subject, such as the type and temperature of the animals being studied, should be taken into consideration when analyzing RFR effects on organisms.

The RFR fields from PAVE PAWS will be similar to existing military and civilian radar systems which have been operating continuously for many years without any noticeable ecological damage. Also, animal behaviorists and ornithologists for over a decade have considered radar as a legitimate tool for studying animal migration, navigation, and homing (Eastwood, 1967; Krupp, 1976; Williams et al, 1977; Schmidt-Koenig and Keaton, 1978).

With respect to insects, Gary and Westerdahl (1978) have summarized a variety of effects caused by exposure of insects to RFR

which have been reported in the literature. The effects ranged from unrest to death, depending on the level and duration of the exposure and the species studied. The lowest levels of any reported effects were somewhat below 10,000 microwatts/cm$^2$ at frequencies of 9 to 10 GHz. Abnormal development of beetle pupae were reported at these levels.

In summary, no significant ecological effects from PAVE PAWS main beam exposure are expected. At most, only a few airborne individuals of fauna common to the area might be affected in a localized area near the radar, and even these effects may not be hazardous.

3.1.2.2.1.2 Ground and Near Ground-Level Exposure

Plants and animals at the ground and near-ground levels will be exposed to power densities much lower than those of the main beam. Table 3-3 presents data on the approximate areas and locations of land near PAVE PAWS which are calculated to receive various power densities at ground level. (Exposure at higher elevations can be calculated from Figures 3-3 through 3-8, pp. 3-5 through 3-10).

Table 3-3

AREA AND LOCATION OF LAND TO RECEIVE VARIOUS POWER DENSITIES AT GROUND LEVEL FROM PAVE PAWS[a]

| Ground Level RFR Power Density (microwatts/cm$^2$) | Area of Land To Be Affected (Acres) | Location of Land and Habitat Type to be Affected (see Figure 1-3, p. 1-4) |
|---|---|---|
| 500 - 4,400 | 0.5 | Within security fence; cleared land, no vegetation |
| 30 - 500 | 40.0 | Extending from security fence to the 1,000-ft exclusion fence; pitch pine, scrub oak woodland |
| 5 - 30 | 35.0 | Extending from the exclusion fence to 900 ft beyond the exclusion fence; pitch pine, scrub oak woodland |

[a]Based on data for the basic system as provided in Section 3.1.1.1, p. 3-2, and Table A-4, p. A-26.

Power density levels incapable of producing substantial heating evidently have no adverse effects on living organisms (Section 3.1.2.1.9, p. 3-60). The only ground area which will receive RFR power density levels greater than 500 microwatts/cm$^2$ is a small (less than one-half acre) area of land immediately adjacent to the radar. This area has been cleared of all vegetation and has a 9-ft high security fence that will keep large animals, including deer, from straying into the area.

With respect to the thermal effect of producing cataracts, the value of a cataractogenesis threshold has been reported by a number of independent investigators as being about 150,000 microwatts/cm$^2$ (Section 3.1.2.1.9, p. 3-60). Thus, it appears there is essentially no possibility that RFR from PAVE PAWS will cause cataracts (or any other noticeable abnormalities) in deer and other large mammals in the area.

The pitch scrub oak woodland habitat immediately surrounding the security fence will receive, at most, 500 microwatts/cm$^2$ of RFR. In the area from the security fence to the 1,000-ft exclusion fence, the power density falls to 30 microwatts/cm$^2$. By comparison, some towns with broadcast transmitters have power densities of 10-50 microwatts/cm$^2$. About 900 feet from the 1,000-ft exlusion fence, the power density falls to 5 microwatts/cm$^2$, a power density that approximates maximum environmental levels of RFR in many cities (Section 3.1.2.1.2, p. 3-23). A total of about 75 acres of natural habitat will be exposed to power densities of RFR that exceed that power density. As with potential effects from the main beam, any possible impacts arising from ground level exposure would be very localized. Although the deer in the area will be able to jump the 6-ft exclusion fence, it is not expected that they will be affected by the densities of 500 microwatts/cm$^2$ and lower. Even if unexpected effects did occur, the 75 acres of woodland surrounding the radar provide sufficient habitat for only small populations of deer and other large mammals.

In summary, ecological effects from ground or near-ground level RFR exposure from PAVE PAWS are not anticipated, due to the very low power density levels in the surrounding area.

3.1.2.2.2 <u>Non-RFR Effects</u>

The operation of PAVE PAWS will have the familiar effects of any facility that uses a road and occupies grounds and structures in the Cape region. The most noticeable of these effects will probably result from the potential increase in fires, from increased noise levels, and from increased access into the area.

A slight increase in the number of accidental fires may occur with the greater number of people (approximately 200) entering the site. However, since the site is under continual supervision by

guards twenty-four hours a day, any fire which may be started would be quickly detected. The ecological impact of any fire is minimized because the local biota is tolerant to fire. The new growth of vegetation in the area would probably stimulate repopulation of some of the local wildlife populations.

Intermittent and continuous noise will be created by the operation of the generators, automobiles, and cooling towers (see Section 3.1.2.4.4, p. 3-78). Most vertebrates that use sound for communication are sensitive to sounds in the range of 0.5 to 6 kHz, the frequency range of much of the generator noise. Consequently, the intermittent operation of the generators may interfere somewhat with the behavior of the local fauna, primarily with that of nesting birds up to 2,000 feet from the facility. However, the loudest noises (70 dB) that can be expected in uncleared areas at least 100 feet from the radar will be one-hundredth that which could permanently damage the hearing of songbirds and small mammals (Benitez et al., 1972; Carder et al., 1971; Marler et al., 1973; Miller et al., 1963; Saunders et al., 1974). In addition, these noise levels would generally only occur for approximately 15 hours per week.

The physical presence and movement of people and their motorized vehicles will probably also result in some minor behavioral effects on animals near the access route into the site. All of the effects discussed in this section are expected to be negligible increments to existing problems throughout the Cape.

### 3.1.2.3 Electromagnetic Environment

3.1.2.3.1 PAVE PAWS Contribution to the Electromagnetic Environment. Operation of PAVE PAWS will certainly change the electromagnetic environment during its pulses, generally over the frequency bands of its coverage, and within the space its pulses reach. (Appendix D comprises a detailed analysis of the change.) The effect of this change can be described as an actual addition to the environment, or it can be described in terms of how the change affects other systems and thus becomes perceptible to those using the systems. In this section the addition to the environment is described.

Civilian use of the radio spectrum is under the control of the Federal Communications Commission; government use is under the control of the National Telecommunications and Information Administration, formerly the Office of Telecommunications Policy (OTP). Since PAVE PAWS is a military system, a detailed application for spectrum support was made through Air Force channels to the Interdepartment Radio Advisory Committee of the OTP, which subsequently authorized operation of the radar.

PAVE PAWS transmits pulses in the band from 420 to 450 MHz, which is within what is commonly called the UHF (Ultra-High

Frequency) band. The band is shared with various other radars, with radar altimeters in aircraft, and with the Amateur Radio Service, which currently has two satellite relays in orbit. The band immediately below that of PAVE PAWS (410 to 420 MHz) is used exclusively by the Federal government for both fixed links and mobile services. The band immediately above (450-460 MHz) is used for other land mobile services. Users of these services include public safety groups (police, fire, forestry, highway, and emergency services), industries (power, petroleum, pipeline, forest products, and so forth), and providers of land transportation (taxis, railroads, buses, trucks). The UHF TV channels -- channels 14 through 83 -- are in the band from 470 to 890 MHz.

Each of the two faces of PAVE PAWS is essentially an independent radar system. Each face transmits a narrow beam of energy; within a few tens of millionths of a second, the beam is switched electronically to some other direction. Each face of the radar can form beams over an azimuthal angle of 120 deg, so that the radar can observe in a 240-deg azimuth from 347 deg to 227 deg.

PAVE PAWS will generally be searching for objects rising through the surveillance volume (usually at an elevation angle of 3 deg but sometimes higher), but some time will be used for tracking objects previously found. When searching, it will transmit closely spaced clusters of pulses -- a pair of 8-ms pulses, a triplet of 5-ms pulses, or a sequence of triplets of 0.3-ms pulses. Its pulse widths for tracking are selected by the PAVE PAWS computer and are determined by the distance to the target, the target trajectory, and the like. When searching, the beams from the two faces move in synchronism; when tracking, the beam from each face is independent.

PAVE PAWS has 24 evenly spaced frequency channels, between 420 and 450 MHz, and it changes frequency for each succeeding pulse, according to rules programmed into the system's computers and under the influence of the actions of any targets being tracked. It generally changes frequency by at least 3.6 MHz from pulse to pulse.

The pulse and frequency-switching behavior of PAVE PAWS cannot be predicted exactly, because, although controlled by rules programmed into the computer, the behavior depends on the number and orbital characteristics of the objects it is called upon to track. Only average characteristics of PAVE PAWS emissions can be predicted.

PAVE PAWS points its main beam at an angle of 3 to 85 deg above the horizon. However, only about half of the power is in the main beam. There is also a concentration of power in the first sidelobe, which is at a maximum about 3.4 deg off the main beam axis for the basic system, and 2.4 deg off for the growth system (see Figure D-4, p. D-13). The maximum power density of

the first sidelobe is 1/100 or less of the maximum power density of the main beam. PAVE PAWS also has many minor concentrations of power in higher-order sidelobes, at increasingly greater angles off the main beam axis. The power density of the greatest of these is 1/1,000 or less of the main-beam power density. Most of these higher-order sidelobes are much weaker than the maximum, and the averages are about 1/6,300 and 1/13,000 of the main-beam power density for the basic system and the growth system, respectively.

The main beam does not illuminate the ground and is not used to track aircraft. However, an aircraft flying within the surveillance volume is illuminated by some sort of main-beam surveillance pulse about once every 1.4 seconds and by the first sidelobe about twice as often. In the surveillance volume, as well as outside it, the aircraft is illuminated by the higher-order sidelobes. The higher-order sidelobes extend in all directions in the hemisphere centered on each face, so an object illuminated by them receives a signal on each pulse -- surveillance and tracking. Objects on or near the ground are illuminated mainly by the higher-order sidelobes, and, in some areas, occasionally by the first sidelobe (basic system only, see Section 3.1.1.1, p. 3-2, and Figure A-7, p. A-22).

3.1.2.3.2 <u>The Effects of PAVE PAWS on the Electromagnetic Environment</u>. PAVE PAWS' contribution to the electromagnetic environment may affect people or systems already using the electromagnetic environment and systems not intended to receive electromagnetic energy. Other users of the spectrum include TV, radio, and other radars; systems or processes not intended to receive electromagnetic energy include cardiac pacemakers, electroexplosive devices, and fuel handling processes.

In the calculations and predictions of interference presented in Appendix D and summarized here, many of the terms and factors had to be assumed. Medians and averages were often used, but conditions under specific circumstances can deviate far from the average. For ground-based receivers, worst-case assumptions (which would overstate susceptibility to interference) were generally used. Effects of interference on various receiver systems were evaluated subjectively on the basis of engineering judgment -- only interference tests could resolve some of the uncertainties, and some such tests have been undertaken during the initial operations of PAVE PAWS. The interference effects of the growth system will be similar to those of the basic system, but experienced at greater distances.

3.1.2.3.2.1 <u>Telecommunication Systems</u>

3.1.2.3.2.1.1 <u>The Basic System</u>. Two types of military aircraft radar altimeter share the spectrum with PAVE PAWS, but their

operation is to be eventually discontinued. The OTP has extended the cut-off date several times already. Neither type is used for landing approaches and one is not to be used within 50 mi of land. (These altimeters supplement the required barometric altimeter, which is unaffected by PAVE PAWS.) It is known that land-based radars interfere with these altimeters. Study indicates that both types will be affected when they are in radio line-of-sight of PAVE PAWS. One type might continue to provide useful altitude information, but the other may not.

PAVE PAWS had been expected to interfere strongly with an ionospheric radar operating at 440 MHz and located at the MIT Lincoln Laboratory Millstone Hill Field site, Westford, Massachusetts. However, in the first 550 hours of testing, no interference had been noted. This radar can use either of two reflectors -- a vertically pointing 220-ft dish or a rotatable 150-ft dish that can be directed towards the horizon. PAVE PAWS was expected to interfere with the sidelobes of both. When the rotatable dish is pointed in the direction of PAVE PAWS, interference was expected to saturate the receiver's front end. Regardless of the dish's direction, interference was expected each time PAVE PAWS radiated on 440.4 MHz (generally approximately three times each second). Less extensive interference was expected when PAVE PAWS operated at other frequencies in its band; PAVE PAWS could be made to do so except when operations might require that the entire frequency complement be used.

PAVE PAWS was also expected to interfere with the AN/FPS-35 Air Force air-search radar at Montauk Point, Long Island. Again though, in the first 550 hours of PAVE PAWS testing, no interference was noted. It was expected to receive PAVE PAWS in its sidelobes as well as in its main beam, causing disturbing indications on the operator's radar display scopes. This radar operates on a single selectable frequency in the 425-450 MHz band. It is scheduled to discontinue service in 1980, but in the meantime, any interference could be mitigated when the operations of PAVE PAWS permit it to use less than its full complement of frequencies.

The Amateur Radio Service (the Hams) shares the entire 420-450 MHz band with PAVE PAWS and the other radar systems. It is a secondary service, not permitted to interfere with the operation of any government radar and without guaranteed protection against interference. In addition to fixed and mobile systems, the amateurs operate two orbiting satellite transponders and conduct moon-bounce communications. One satellite receives on 432 MHz and the other transmits on 435 MHz. Although interference (from higher-order sidelobes) with them and with moon-bounce is possible when the satellites (or the moon) are above the horizon, it could be alleviated, operational requirements permitting, if PAVE PAWS could discontinue its use of these two frequencies when the satellites (or the moon) are in sight. (In operation, PAVE PAWS avoids illumination of the moon with the main beam.)

In addition to the satellite operation, the amateur radio service operates several 144-148 MHz repeaters and a repeater operating at about 445 MHz on Cape Cod. The third harmonic of the 144-148 MHz repeater outputs and mobile operation could cause interference to PAVE PAWS. There may be mutual interference between the 445 MHz repeater and PAVE PAWS. The interference could be alleviated by PAVE PAWS not using the problem frequencies, additional filtering on the input and output of the repeaters, or changing the repeater location.

A UHF/AM receiver located in a fire tower 3 miles from PAVE PAWS operates on 381.4 MHz. PAVE PAWS is not expected to interfere with this receiver.

PAVE PAWS will not interfere with a UHF/FM base station operated on 419.3 MHz, licensed to the Department of Justice, and located in Boston, 36 miles away from the radar. However, interference to mobile units operating in the vicinity of PAVE PAWS can be expected. We estimate that interference pulses caused by emissions from the lowest frequency of PAVE PAWS (421.3 MHz) that occur about 3 times per second could be detected about 9 miles from the radar. At that distance, the effect of the pulses would probably be negligible, but if the vehicle came closer to PAVE PAWS, the intensity would increase. However, this interference is unlikely to be a problem for the Department of Justice. Because of the distance between Otis AFB and Boston, the system's mobile-to-base station communications might not be reliable, and the net would probably not be used at these distances.

Barnstable County is licensed to operate a UHF/FM base station on 453.7 MHz. The city of Barnstable is approximately 16 miles from PAVE PAWS. The radar is not predicted to interfere with the base station receiver. However, mobile units within about 5 miles of PAVE PAWS could be interfered with; the interference may not be a problem, and perhaps it could be eliminated by receiver squelch adjustment.

Interference with aircraft UHF/AM links in the upper portion of the 335.4-399.9 MHz military band is likely. Although PAVE PAWS is not expected to interfere with a UHF/AM ground receiver at the Otis flight facility, 6 miles away, interference with military aircraft is expected. It is likely that communications from the ground to the aircraft would generally override the interfering signal. Thus, although the pulsed interference might be audible to the pilot, it would probably not disrupt the air-ground and ground-air communication links. Distances at which the effects would occur depend on the portion of the UHF/AM band used for the communication.

Interference with various air-navigation systems (besides communications and in-band radar altimeters) has been considered. TACAN and VORTAC stations provide range and distance information

to aircraft. The TACAN or VORTAC stations near Cape Cod use frequencies that are not affected by PAVE PAWS, except that an ++ airborne receiver could be affected by 1 of the 24 PAVE PAWS frequencies. However that signal is not expected to cause any loss in the effectiveness of the equipment. Tests with the airborne components showed that neither of the two samples tested was affected at power density levels corresponding to basic-system main-beam illumination at about 3 and 5 miles. (These were the maximum power density levels available from the testing equipment.) The effects could be negligible at considerably smaller distances.

High-power measurements have also been conducted on other airborne navigation system receiver units. The term high-power effects is used to describe the coupling of energy directly into an electronic system through its case or internal wiring. The indications were that some effects were experienced at power density levels corresponding to illumination by the main beam at distances as great as 3 miles. These effects would depend strongly on the frequency of the interfering (PAVE PAWS) signal and the strength of the desired signal. Some measurements have been done at PAVE PAWS frequencies (but not using PAVE PAWS pulse widths or pulse rates) to learn the interference levels that would cause effects in home high-fidelity stereo units, AM radios, land-mobile transceivers, and so on. Very small samples were used -- sometimes only one or two items. On the basis of these limited tests, we believe it unlikely that effects would be noted at the distances from PAVE PAWS at which such systems would be operated.

Of the six TV channels that consider Barnstable County to be in their Grade A service area, interference is expected only on WJAR, Channel 10. Available test data are insufficient to define the extent of the problem clearly. However, it appears that a small percentage of the Channel 10 viewers as far as about 20 miles from PAVE PAWS and in its line-of-sight may experience reception degradation. + Susceptibility of TV sets to interference varies widely from unit to unit. Those affected at 20 miles would be the more susceptible TV receivers; some in the line-of-sight at distances of less than a mile would not be affected. TV sets that are protected from the PAVE PAWS signal by intervening hills and by vegetation, which will absorb the radar signal, can be much closer (say 2 or 3 miles) without effect, and some very limited tests in Sandwich have failed to show effects beyond about 3,000 ft. A simple and inexpensive filter designed to be attached to the back of a TV receiver (and provided by the Air Force on request) may permit unaffected reception of Channel 10 even within line-of-sight and at distances as close as the 1,000-ft exclusion fence. The interference is caused by only 6 of the 24 PAVE PAWS frequencies -- those from 431 to 437 MHz. This band includes the frequencies used by the Hams, as mentioned above. If operational requirements permit, discontinuing use of these six frequencies would eliminate problems with both Hams and TV. Experiments could

determine whether discontinuing the use of fewer than six frequencies would accomplish the same end.

3.1.2.3.2.1.2 The Growth System. The effect of the growth option will be to increase the radiated pulse power densities in the main beam and the first sidelobe by a factor of four. Thus, at a given distance, the power density increases by that factor of four. Power density decreases by this same factor of four as the distance doubles. Therefore, the pulse power densities found in the main beam or the first sidelobe at some particular distance for the basic PAVE PAWS system would be found at twice that distance for the PAVE PAWS growth system. The effect of this is to double the distances at which effects are expected. Of course, only airborne objects are illuminated by the main beam.

At any given location illuminated only by the higher-order sidelobes, the power density of the growth system simply doubles. A particular power density would then be found for the growth system about 1.4 times as far away as it would be found for the basic system.

For receiver systems susceptible to the basic system, the kind of interference effects of the growth option will be generally the same.

We expect that the growth system will not interfere with the Barnstable UHF/FM base station. The uncertainties in the predictions, previously discussed for the basic system, also apply for the growth system. The mobile units will first detect PAVE PAWS interference about 7 mi from the radar.

A Coast Guard receiver at 1.74 GHz is located 3.2 mi from PAVE PAWS and in its line-of-sight. The PAVE PAWS fourth harmonic is not expected to interfere with the receiver. We expect that the fourth harmonic frequency generated by PAVE PAWS will be significantly below the radar specification for the following reason. Odd-order harmonic frequencies typically have higher power than even-order harmonics. Then if the third harmonic frequency meets the specification, the fourth harmonic will be significantly less powerful, and interference will not occur even for the growth system. Further, any foliage close to the line-of-sight path over the hilltop will severely attenuate the fourth harmonic. Calculations for the growth system indicated that no interference to the Coast Guard microwave system will be produced.

3.1.2.3.2.2 Effects on Pacemakers, Electroexplosive Devices, and Fuel Handling

3.1.2.3.2.2.1 The Basic System. A design susceptibility threshold of 200 V/m has been suggested for cardiac pacemakers in a

draft standard by the Association for the Advancement of Medical Instrumentation. Newer models of cardiac pacemakers have been tested against signals very similar to those to be radiated by PAVE PAWS, and most are unaffected by pulsed fields as high as 330 V/m. The pulse field in line-of-sight at ground level at the 1,000-ft exclusion fence is only about 42 V/m. Therefore, it seems unlikely that an earthbound owner of a pacemaker with a susceptibility threshold of 200 V/m would be affected by PAVE PAWS. +

The suggested 200 V/m susceptibility threshold will be regularly exceeded by the PAVE PAWS signal only in the main beam surveillance volume at distances within 1 mile of the radar -- a location that can be reached only by helicopters and fixed-wing aircraft disregarding basic flight safety. Almost the entire volume is in an existing restricted area (No. R-4101). The surveillance volume swept by the main beam is quite small and no prudent flyer would enter it or could keep his fixed wing aircraft in it for more than a few seconds at a time. Viewed from above, the volume is a 240 deg sector extending 1 mi from PAVE PAWS; in cross-section it is a narrow wedge, with a maximum thickness of only 200 ft at a mile from PAVE PAWS (see Figure D-15, p. D-70). At a half-mile it is only 100 ft thick. Entering the volume requires flying below about 380 ft. No commercial flight paths traverse the volume. It presents no hazard to pacemaker owners whose pacemakers meet or exceed the suggested 200 V/m susceptibility threshold. If the aircraft provides any shielding at all, the volume of concern becomes much smaller. + + + + + + +

Despite very real improvements in lowering the susceptibility of newer models of pacemakers, some that are susceptible at levels well below 200 V/m are still in use. However, pacemakers are replaced every 2 to 5 years when their batteries are exhausted. The physicians who replace them have the opportunity to implant pacemakers with improved interference-rejection abilities.

Air Force Technical Manual T.O. 31Z-10-4, on electromagnetic radiation hazards, instructs that fuel handling operations (fueling of aircraft and so on) should not be undertaken in fields with pulse power greater than 5,000,000 microwatts/cm$^2$. The growth system pulse power at the 1,000-ft exclusion fence is only about 5,700 microwatts/cm$^2$. Therefore, it is not anticipated that PAVE PAWS will constitute a hazard to fuel handling operations.

+

Because the power densities that constitute a hazard to electroexplosive devices (EEDs) can be encountered at ground level

only within a few hundred ft from the radar, only the higher-order sidelobes need to be considered for ground level exposure. The safe power density criteria are:

- 75 microwatts/$cm^2$ for exposed EEDs
- 663 microwatts/$cm^2$ for EEDs in taxiing aircraft
- 10,000 microwatts/$cm^2$ for EEDs stored in metal containers.

The most stringent criterion (that for exposed EEDs) is not exceeded at distances beyond about 800 ft from the radar. The main beam can illuminate EEDs in or on aircraft. The safe power density criterion for airborne EEDs is 10,000 microwatts/ $cm^2$. The contribution of power by the main beam is large relative to that of all the sidelobes, but the criterion is exceeded only within about 600 ft from the radar and within 100 ft of the ground. No prudent flyer would enter this volume in disregard of basic flight safety. Therefore EEDs will not be jeopardized by PAVE PAWS.

3.1.2.3.2.2.2 The Growth System. As discussed before, the power density at a given ground location in the far field doubles, and the distance along the ground at which some effect will occur for the growth system is about 1.4 times as great (in higher-order sidelobes) as it is for the basic system. The most sensitive EEDs can safely be handled outside of about 1,500 ft; fuel handling will be safe outside the exclusion fence. In the main beam and first sidelobe, the power density at a particular distance quadruples; any particular effect caused by the basic system would be experienced at twice the distance under the growth option. The volume within which the field exceeds 200 V/m becomes larger in radius and shallower, but it still is not entered by commercial flights or by prudent flyers. +

### 3.1.2.3.2.3 Effects Observed During Radar Testing ++

#### 3.1.2.3.2.3.1 Instrumentation in Helicopters ++

PAVE PAWS has been observed to produce false indications in instruments in helicopters. Two Army OH-58A helicopters each noted misleading indications in their instruments as they approached to within about 2500-3000 meters (1.6-1.9 miles) of the radar and within the main beam surveillance volume. They had previously received clearance to enter the restricted area. In both helicopters, the fuel gauge indicator suddenly began to register falsely high and, at the same time, the pilots were alerted by lights and an audio alarm meant to indicate low engine RPM. These latter are designed to alert the pilot to a potential engine (or rotor) failure. The pilots quickly realized that there

were no engine problems and that the alarm indications themselves were erroneous. There was no effect on the actual performance of the helicopters.

The helicopters, at about 2 km, were being illuminated with pulse power densities of about 48 dBm/m$^2$ or 7,300 microwatts/cm$^2$. The effects depended on the orientation of the helicopter relative to the radar; they ceased as the helicopters turned away from PAVE PAWS. These are examples of high-power effects. The fuel gauge problem in OH-58A helicopters is not new; that gauge is known to give false indications when an onboard AN/ARC-114 FM radio is keyed on.

The FAA is active in investigating potential problems in air navigation. Flights were made on 9 and 10 February 1979 to test the effects of the radar on several air navigation instrument types. They also paid special attention to note abnormal operation of their cockpit instruments; no abnormalities were noted. The FAA trip report concludes, "Since the radar's burst of RF energy occurs for only a fraction of a second on a specific frequency, and appears to occur only one time in several minutes, it is concluded that the radar does not present potential interference to our navigational facilities." (FAA, 1979)

Further tests were conducted on 22 March 1979, with helicopters carrying measurement instrumentation. The tests involved the Massachusetts National Guard and the U.S. Coast Guard, and it was learned that the Coast Guard helicopters were not affected as close as the 1,000 ft exclusion fence. A UH-1 helicopter experienced flashing of its low-rpm indicator light when within about 1 mile of the radar. Work is underway to establish procedures for Army helicopters operating near the radar, and a Notice to Airmen (NOTAM) has been issued as follows:

"<u>NOTAM</u>

Aircraft operating below 2,000 feet and within three miles of the PAVE PAWS radar site located in restricted area 4101, Bourne, Mass., may experience momentary erratic operation of cockpit instruments or navigational equipment. Pilots are encouraged to submit reports of such occurrences to the nearest FAA Air Traffic facility."

3.1.2.3.2.3.2 <u>Interference to a Nearby Land-Mobile Repeater</u> ++

A repeater (radio relay) operating in the non-federal-government land-mobile band with its receive frequency at about 468 MHz is physically so close to PAVE PAWS that it suffers interference. The repeater is used by an emergency medical service (EMS), and as such it may be needed to transmit analog medical data needed to monitor the conditions of illness and

accident victims. The presence of this EMS system was not known, and so it was not analyzed when the Draft EIS was prepared. PAVE PAWS has been found to interfere with the transmission of electrocardiograms (EKGs) via the repeater. The repeater accepts and retransmits PAVE PAWS signals when its squelch is held open by a desired signal, thus producing an unacceptable EKG recording.

Efforts are now under way by the Air Force to correct the interference problems. Having tried simpler solutions, the Air Force plans to relocate the EMS repeater station to some place behind the radar, from which it will still serve its desired area but will not suffer interference from PAVE PAWS. This Air Force-financed move is scheduled to be completed by 18 June 1979.

3.1.2.3.2.3.3 <u>Powerline Waveform Irregularities</u>

There have been complaints that the PAVE PAWS dc power supply system is causing a 720 Hz ripple on the 60 Hz voltage of the power distribution system in the Sandwich area. Such a ripple could occur as the result of the rectification of the 60 Hz supply to provide the dc needed by the radar's solid-state circuitry. It would not affect most other devices, appliances, or systems connected to the power distribution system. Users of power for lighting, heating, refrigerating, and for the operation of motors of all sorts would not be affected. However, some sensitive scientific equipment may not tolerate the low-level 720 Hz component on the 60 Hz line voltage. Efforts are underway to define the problem and to seek solutions. Measurements of line voltages have been taken with PAVE PAWS operating on its own power and with it operating on power supplied by New Bedford Gas and Electric Light Company. Resolution of the problem awaits the analysis of the data from these tests.

3.1.2.3.2.3.4 <u>Interference to TV Preamplifiers</u>

Interference has been reported by four TV owners having the same type of TV antenna with a built-in preamplifier. Their distances from PAVE PAWS range from 2 to 20 miles. The interference occurs on all channels, indicating that the interference mechanism is not of the spurious-response type described in Section D.3.1.2.2, p. D-21 The evidence is strong that the broad-band preamplifier is sensitive to the PAVE PAWS pulses. Work is under way to determine whether an Air Force-supplied filter (not the same one described in Section D.3.1.2.7, p. D-32) will alleviate the problem.

3.1.2.4 <u>Soil, Water, Air, Noise and Solid Waste</u>

3.1.2.4.1 <u>Soil</u>. Inspection of the PAVE PAWS site showed that the top of Flatrock Hill had been leveled for construction. Only

minor rill and gully development on the unvegetated portions of the construction site was evident, and no similar evidence of incipient erosion was noted in the nearby vegetated areas down-slope from the site. Although the soil is very sandy, it is not prone to significant erosion because it contains abundant gravel and cobbles and is highly permeable. Therefore, no significant erosion is expected to result from the operation of PAVE PAWS on Flatrock Hill.

3.1.2.4.2 Water

3.1.2.4.2.1 Water Use. The operation of PAVE PAWS will result in no significant depletion of the groundwater. One water well has been drilled to a depth of 440 ft on the site, and pump-tested at 100 gal/min for 30 hr. The measured drawdown in the well was 14 ft (Jefferson Construction Company, 1978). A 200,000-gal above-ground tank has been constructed for water storage. Water demands for fire control, personnel use, and equipment cooling and washing are estimated at about 10,000 gal/day (7 gal/min) (Shean, 1978). This volume of use is substantially below the rate at which the well was tested, and is equivalent to the daily requirements for a town with a population of 70. Therefore, because the well test indicated that drawdown in the aquifer from the operation of PAVE PAWS will be minimal, no problems associated with depletion of ground water should result.

3.1.2.4.2.2 Water Quality. No effect on regional water quality is expected. The quantities of contaminants present are so small that it is unlikely any will reach the zone of groundwater saturation and thereby contaminate the aquifer. The groundwater table is at a depth of approximately 230 feet below the land surface at the project site (LeBlanc and Guswa, 1977). Contamination of other water supply wells also appears unlikely, because no wells are located within a mile of Flatrock Hill. In addition, drainage of surface water is discontinuous in the vicinity of Flatrock Hill, which indicates that contamination of surface water sources is highly unlikely.

One potential for contamination of the aquifer is the diesel fuel handling and storage facilities. Three 40,000-gal, steel, underground tanks have been installed for storing diesel fuel. The tanks and all buried pipes have been wrapped in asphalt to prevent corrosion, as recommended by CCP&EDC staff. Both the fuel-loading site at the storage tanks and the generator area of the power plant have been installed with a gravel and concrete drainage system that leads to an oil/water separator and a drain field. The system should capture any minor amounts of fuel, oil, or grease that spill in the area. The oil will be periodically pumped out of the separator to assure its effectiveness.

Although outside power is cheaper and will be used whenever possible, the diesel generators will be operated for testing, deicing, and in case of a power failure outside the base. Given the design of the facilities and the proposed operating conditions (refer to Section 3.1.2.4.3), a major spill seems an unlikely prospect.

Domestic sewage is captured and diverted to a leach pit where it undergoes anaerobic degradation before being discharged through subsurface drains. Further filtration and purification of the wastewater occurs as the effluent percolates down through 200 ft of fine sand and gravel before reaching the water table. This system operates the same as any large septic tank; no permit was required because it is located on a federal reserve.

A 24,000 volt transformer is located on an earth mound on the west side of the PAVE PAWS facility (Shean, 1978). A cyclone fence surrounds the transformer and several lightning rods are stationed nearby. In the unlikely event that the transformer ruptures, the dielectric fluid would spill onto the ground surface. There are no provisions to contain the spill, but aquifer contamination is highly unlikely because of the great depth to the zone of ground water saturation.

Discharge of cooling tower blowdown will have no effect on regional water quality. Cooling of the diesel generators and the PAVE PAWS facility is supplied by two separate systems: the tower water system, and the closed-loop system (Shean, 1978). The closed-loop system supplies cooling to both the solid-state modules and the building's air handling system. No discharges occur from this system. The tower water system, on the other hand, cycles water from the cooling tower through the chiller. The chiller then cools the freon which subsequently cools the liquid in the closed-loop system. The water in the closed-loop system is treated with chemicals to maintain standard pH and hardness. The conductivity in the tower water system is continuously monitored. When it rises above 750 micromhos, approximately 500 gallons of water are purged from the system (cooling tower blowdown) and are replaced by fresh water from the storage tanks. The purged water is discharged to the sanitary sewer system. The discharge water is higher in total dissolved solids and in temperature than the domestic sewage, but neither of these characteristics will adversely affect the operation of the leach pits.

Storm runoff from the site travels as sheet runoff into the surrounding vegetated areas, where it is absorbed into the soil. Although the runoff will contain road salt, oil, and minerals, the quantities of such materials are expected to be no greater than those from any other similar concentration of buildings, parking lots, and roads.

Drainage of surface water in the area is poorly developed. There are no ponds or lakes within 1.5 mi of the site, and no

streams or gullies exist to direct runoff from the site into a defined surface water body. Thus, no potential for surface water contamination exists.

3.1.2.4.3 <u>Air</u>. During the operation of PAVE PAWS, air pollutants will be emitted by the vehicles of the employees and by the diesel electricity generators in the power plant.

The 200 PAVE PAWS employees will generate only a very small portion of traffic on the Cape. Because the employees will live in various areas on and off the Cape, their traffic will be distributed and would represent only fractions of a percent increase on any one major road. Consequently, air pollution from traffic associated with PAVE PAWS will not cause any discernable degradation of the air quality on Cape Cod.

The PAVE PAWS facility requires 2.5 MW for normal operation compared with a total of 500 kW for the two FSS-7s that PAVE PAWS replaces. Power will be drawn via overhead transmission lines from the commercial power grid. The Canal Electric Power Plant, which supplies power to the grid near PAVE PAWS, uses fuel oil. The on-site power plant (see Figures 1-2 and 1-3, pp. 1-3 and 1-4) will serve as a backup in case of an emergency such as a severe storm or an overload that could cause a blackout or brownout in the commercial power grid. Once or twice during winter seasons, the exposed antenna elements may require heating to remain free of ice. The one megawatt of power required for deicing will be generated on-site to avoid an increase in peak demand charges from the commercial power company. In addition to possible emergencies and deicing, the diesel-electric generators will be run regularly for operational exercises and maintenance. In a typical week, the power plant would run 4 of the 6 engines for approximately 15 hr, during which time the power plant will produce 99 lb/hr of oxides of nitrogen ($NO_x$), 2.2 lb/hr of hydrocarbons (HC), and 6.6 lb/hr of carbon monoxide (CO). For these estimates, we assumed each of the engines will produce 625 kW with approximately 2,500 hp. We also used emission rates of 4.5 grams/hp-hr for $NO_x$, 0.10 g/hp-hr for HC, and 0.30 g/hp-hr for CO. Emissions of particulates and sulfur dioxide are negligible (Gotterba, 1978).

Pollutants in such small amounts probably will not be measurable at the boundaries of Otis AFB, especially considering that the Canal Electric Power Plant is only 2 mi away. Thus, the PAVE PAWS power plant should not adversely affect the regional air quality by a detectable amount.

To produce 2.5 MW for PAVE PAWS, a commercial power plant (usually the Canal Electric power plant) will emit slightly more air pollution (than when not supplying PAVE PAWS) by the following amounts: 1.4 lb/hr particulates, 14 lb/hr sulfur dioxide, 0.53 lb/hr carbon monoxide, 0.35 lb/hr hydrocarbons, and 0.35 lb/hr of

oxides of nitrogen. Those estimates are based on the assumed use of fuel oil with a 0.5% sulfur content. These increments of pollutants are unlikely to have a measurable impact on regional air quality.

3.1.2.4.4 Noise. Noise will be generated during the operation of PAVE PAWS by the cooling equipment and by the diesel generators in the power plant, both of which are located directly behind the radar building.

The cooling tower (described in Section 3.1.2.4.2.2, p. 3-77) operates continuously; from 20 ft, its noise level is estimated to be approximately 60 dB. At the guard tower, approximately 125 ft from the cooling towers, the noise level from the cooling towers is about 44 dB.

The diesel generators in the power plant will operate on an irregular schedule as required for power and maintenance. During operation, the generators will produce approximately 68 dB measured from 125 ft away (the approximate distance to the guard tower). Table 3-4 presents the comparative noise levels of familiar sounds.

With a direct path, sound levels are expected to decrease as the distance between the listener and the noise source increases. Table 3-5 shows noise levels from the two PAVE PAWS sources at the gate house on-site, the proposed highway (Route 25), and the existing highway (Route 6). In areas where the PAVE PAWS building itself or natural features such as trees or terrain block the listener, the noise levels are below those listed in Table 3-5.

Route 6 offers the closest point of general public exposure, about 3,500 ft from the radar. At that distance, and with a clear view of the power plant on the back side of the radar building, the noise level at the highway of the cooling towers will be about 15 dB. The diesel generators will produce approximately 39 dB at 3,500 ft. Table 3-4 shows that 15 dB is barely audible and 39 dB is approximately equivalent to the noise level in a library. Furthermore, the typical noise from the highway itself (70 dB at a distance of 18 meters) is sufficiently high to mask the noise from the generator.

If the proposed Route 25 is constructed, the minimum distance of public access will be reduced to 2,700 ft. At that distance, the cooling tower and power plant noise levels will be about 17 and 41 dB, respectively, and will, again, be masked by noise from the highway traffic itself.

Thus, under normal circumstances, the public will not be able to hear noise associated with PAVE PAWS.

Table 3-4

NOISE LEVELS OF TYPICAL SOUNDS AND ASSOCIATED HUMAN RESPONSE

| Typical Sounds | Noise Level (dB)[a] | Response | Conversational Relationships |
|---|---|---|---|
| | 150 | | |
| Carrier Deck Jet Operation | 140 | | |
| | | Painfully Loud | |
| | 130 | Limit of Amplified Speech | |
| Jet Takeoff (60 m) | | | |
| Discotheque | 120 | | |
| Auto Horn (1 m) | | Max. Vocal Effort | |
| Riveting Machine | 110 | | |
| Jet Takeoff (600 m) | | | Shouting in ear |
| Garbage Truck | 100 | | |
| New York Subway | | Very Annoying | |
| Heavy Truck (15 m) | 90 | Hearing Damage (8 hours) | Shouting at 0.61 m |
| Pneumatic Drill (15 m) | 80 | Annoying | Very loud conversation at 0.61 m |
| Alarm Clock | | | |
| Freight Train (15 m) | | | |
| Freeway Traffic (15 m) | 70[b] | Telephone Use Difficult | Loud conversation at 0.61 m |
| Air Conditioning Unit (6 m) | 60 | Intrusive | Loud conversation at 1.2 m |
| Light Auto Traffic (30 m) | 50 | Quiet | Normal conversation at 3.6 m |
| Transmission Line (3-conductor bundle; average during rain at edge of right-of-way) | 47 | | |
| Library | 40 | | |
| Soft Whisper (4.6 m) | 30 | Very Quiet | |
| Broadcasting Studio | 20 | | |
| | 10 | Just Audible | |
| | 0 | Threshold of Hearing | |

[a]Zero dB is equivalent to a sound pressure level of 0.0002 dynes/$cm^2$.
[b]Contribution to hearing impairment begins.

Source: "Noise Pollution," U.S. Environmental Protection Agency, August 1972.

Table 3-5

ESTIMATED PAVE PAWS NOISE LEVELS AT THREE LOCATIONS

| Location | Approximate Distance (ft) | Noise Level (dB) Power Plant | Noise Level (dB) Cooling Tower |
|---|---|---|---|
| Guard Tower | 125 | 68 | 44 |
| Proposed Route 25 | 2,700 | 41 | 17 |
| Route 6 | 3,500 | 39 | 15 |

3.1.2.4.5 Solid Waste. Only a minor quantity of solid waste will be generated at the PAVE PAWS site. It will be disposed at the sanitary landfill on Otis AFB. With the additional load from PAVE PAWS, the present landfill still has sufficient capacity to operate for 25 years (Marr, 1978). The total increase in solid waste from the operation of PAVE PAWS will not approach the volume produced before the curtailment of major Air Force activities on the base in 1973.

### 3.1.2.5 Minerals and Other Resources

Because sand and gravel resources are so abundant in the area, no impacts are expected on these resources as a result of the operation of PAVE PAWS on Flatrock Hill.

### 3.1.2.6 Natural Disasters

The operation of the radar is not expected to affect or be affected by natural disasters, with two conventional exceptions: the potential for fires resulting from carelessness of the staff, and the impacts of an exceptionally strong storm on the structure that houses the radar. The latter effects would be restricted only to the area within or immediately adjacent to the security fence. The former could cause damage to the rest of the base and beyond the base, but that is unlikely in view of the proximity of civilian firefighters accustomed to fighting brush and forest fires.

The expected absence of significant impacts involving perturbation of the radar EMR is based upon two considerations. First, storms or earthquakes severe enough to damage the radar are rare within the area (the design of the radar to withstand at least 120-144 mph winds is conservative). Second, the radar's

performance is insensitive to malfunctions in rather large numbers of its components. Indeed, without the frequent monitoring of individual subarrays, subtle degradation of the radar would go undetected. If the monitoring mechanism were damaged, the instrumentation controlling the radar would immediately alert the radar staff to the problem.

Thus, damage to either the radar or its monitoring mechanism is unlikely, but should either occur, the position and strength of the main beam and the sidelobes should not be affected in any way which would significantly alter exposures.

### 3.1.3 Socioeconomic Impacts

#### 3.1.3.1 Land Use and Aesthetics

3.1.3.1.1 Land Use. Flatrock Hill in the northern portion of Otis AFB was selected for the location of the proposed action for the following reasons:

- The site would allow minimal interference with both artillery range fire and flight patterns.
- Electrical power and services were available.
- Placing the radar there would create the least impact to the surrounding environment.
- The site was the most suitable in light of present land uses.

(Section 4.3, p. 4-2, contains a more detailed discussion of the site selection process.)

The radar facility, which has already been constructed, is located partially within the Otis AFB Wildlife Management Area and partially within the Massachusetts Army National Guard artillery firing range. Approximately 50 acres at the site have been enclosed with a 1,000-ft-radius fence to exclude humans and animals. The land requirement for the radar facility itself, for necessary supporting facilities, and for an access road to the site totals about 10 acres. (Support facilities include those for water supply and distribution, electric power generation and distribution, fuel storage, sewage and wastewater treatment and disposal, parking areas, and a gatehouse.) The access road to the radar facility starts at the intersection with an access road to Route 6 and runs south/southeast across the Otis AFB Wildlife Management Area to Flatrock Hill. The access road is 7,200 ft long and occupies 6 acres of land. The actual radar site has been prepared on 4 acres of land with a security fence constructed around the 100-by-150-ft facility (see Figure 1-3, p. 1-4).

Most of the 50 acres already enclosed in the fence will be left in a natural state. That land is within the exclusion fence and will not be usable for other purposes. The 10 acres of natural woodland that were destroyed to clear the area for the construction of the multistory radar structure, the power plant, and other ancillary structures, as well as the access road, will remain developed for the operational lifetime of the facility. As a result of the new use of this land, the Army National Guard has been required to abandon 4 to 6 of its gun positions on the artillery range surrounding the site.

In summary, assuming that no further land is developed during the operation of the radar, the direct impact on land use at Otis AFB of the PAVE PAWS radar is the withdrawal from other uses of these 60 acres, 4 of which have been developed for the radar structure and supporting buildings. Some 6 acres in the wildlife management area have been required for access road construction, and the rest will remain undeveloped as well as unavailable for other uses. Given that Otis AFB encompasses approximately 20,000 acres, the direct impact on land use of the project is relatively small. The impact on the land would also be short-lived if the Air Force were to return the land to its original state (e.g., dismantles and removes the buildings) after their planned 10-20 year use. + +

Secondary impacts on land use of the proposed action have been examined based on the anticipated new population associated with radar facility operation.

No new uses of the land are anticipated at Otis AFB as a result of the arrival of the 60 PAVE PAWS employees (and their dependents) who will reside there. They will live in existing housing, some of which is currently being renovated for them, and will take advantage of services and facilities already available and in place on the base. Approximately 140 personnel (110 married and 30 single) of the 200 directly associated with operation of the radar are expected to live off-base in the communities surrounding Otis: 90 within the town of Bourne, 30 in Sandwich, 10 in Falmouth and Mashpee, and 10 in other Cape Cod towns. Because adequate housing is available in those areas to accommodate the new, year-round personnel and their families, no new residential construction is expected. But even though housing may be available, some of the new PAVE PAWS employees may choose to build their own homes, thus requiring the use of undeveloped land. While there is considerable acreage in each of the towns categorized as vacant and buildable (at least 8,000 acres), the local planning boards will have to make a determination regarding any proposed construction.

Because any additional secondary employment, stimulated by the need for additional services on the part of PAVE PAWS personnel, will likely be filled by current residents, additional land will

not be required for residential construction to accommodate new secondary or indirect population.

3.1.3.1.2 Aesthetics. PAVE PAWS is visible on Flatrock Hill above the rolling, thickly forested horizon. Figure 3-13 shows the view of PAVE PAWS from midspan on the Sagamore Bridge. Areas of the Cape from which PAVE PAWS can be seen are shown shaded in Figure 3-14. In addition, scattered private residences in and around the village of Sandwich have clear views of PAVE PAWS (see Figure 3-15). The terrain and vegetation block the view from most of Sandwich Center and all of Sagamore, the two villages closest to PAVE PAWS. The radar can be seen from the mid-Cape highway area only at two locations (near the rest stop) at a right angle to the highway. In addition to areas shown on Figure 3-14, p. 3-85 + PAVE PAWS is visible from rather extensive portions of Buzzards + Bay, which is widely used for recreation and other purposes. The + PAVE PAWS building is relatively simple, lacking the complex structures visible on a dish-type radar. The shape of the building is shown in Figure 1-2, p. 1-3. The metal exterior is painted a pale neutral color to render it less conspicuous.

### 3.1.3.2 Demographics and Economics

3.1.3.2.1 Employment. Some 100 military people and 100 civilians, for a total of approximately 200 new personnel, will be new employees at the base with PAVE PAWS operational. Of the new civilian jobs, about 70 will be taken by local people. In addition, it is estimated that the Air Force action will generate enough spending in the area to support the equivalent of approximately 100 secondary jobs. However, because the capacity of many present jobs can be increased, it is expected that only about 70 of these 100 secondary jobs will actually be created. Altogether, approximately 170 new jobs will be opened in Barnstable County because of the operation of PAVE PAWS.

As can be seen in Table 3-6, the level of employment is expected to increase by 0.2% in the county because of the operation of PAVE PAWS. The labor force is expected to increase by less than 1% as well. Unemployment could decline by about 70 people, at most, if all of the secondary jobs were taken by people who were previously unemployed. But because of the highly technical nature of the primary jobs, none are expected to be filled from the ranks of the unemployed.

FIGURE 3-13. VIEW OF PAVE PAWS FROM MIDSPAN ON THE SAGAMORE BRIDGE WITH THE VILLAGE OF SAGAMORE IN THE FOREGROUND

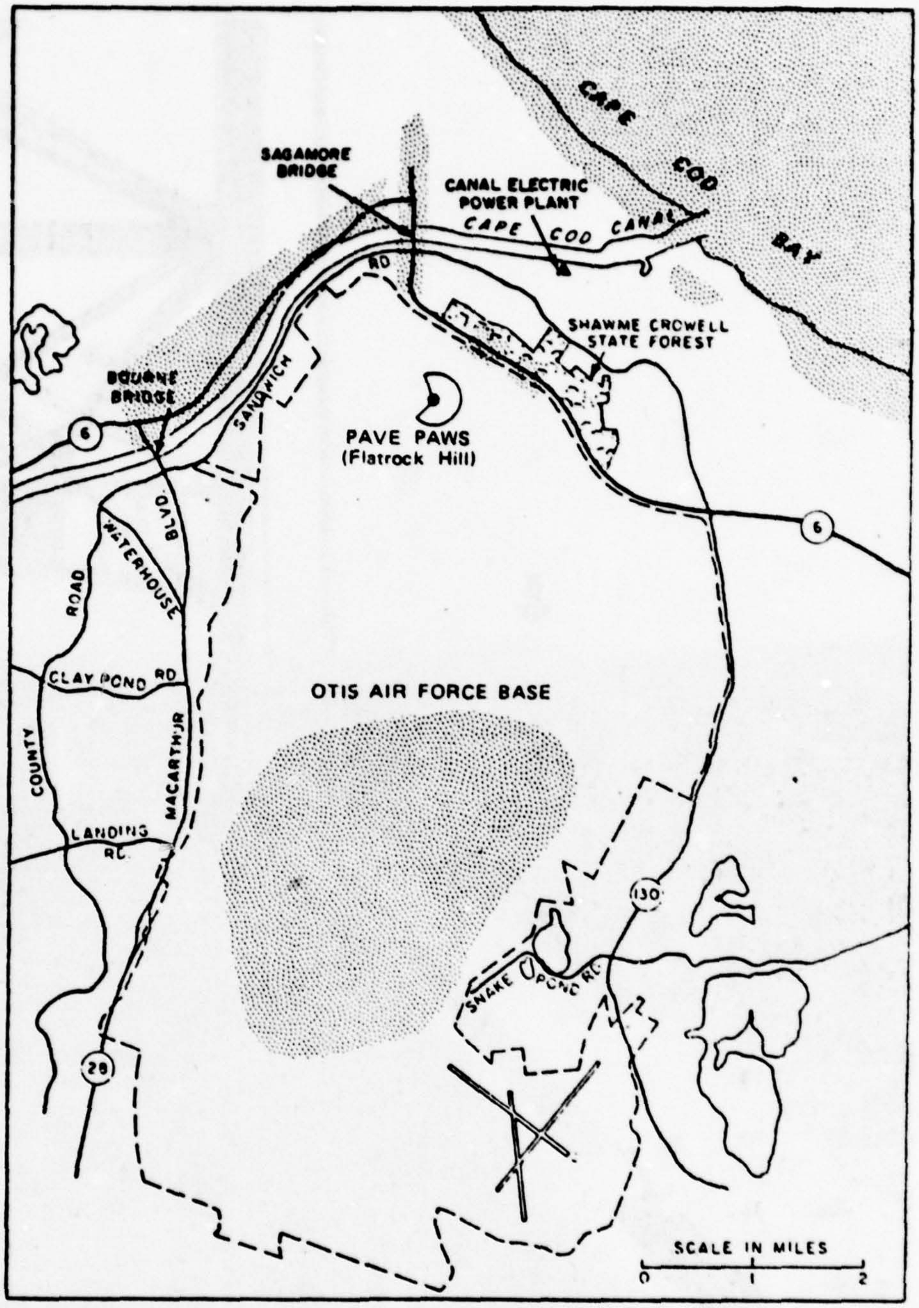


FIGURE 3-14. GENERAL AREAS (SHADED) FROM WHICH PAVE PAWS IS VISIBLE

FIGURE 3-15. VIEW FROM THE TOWN NECK AREA IN SANDWICH OF PAVE PAWS (BARELY VISIBLE TO THE LEFT OF THE HOUSES) AND THE CANAL ELECTRIC POWER PLANT STACK (TO THE RIGHT OF THE HOUSES)

Table 3-6

**EMPLOYMENT**

| Barn stable County | 1975[a] | 1977[a] | Projected 1979 Without AF Action | Annual Average Percent Change 1975-1977 | Annual Average 1977-1979 Without AF Action | Annual Average 1977-1979 With AF Action |
|---|---|---|---|---|---|---|
| Labor Force | 55,338 | 60,901 | 67,000 | 4.6 | 4.6 | 4.7 |
| Employment | 47,850 | 53,993 | 61,000 | 5.7 | 5.7 | 5.9 |
| Unemployment | 13.5% | 11.3% | -- | -- | -- | -- |

[a]Joe Galvin, Employment Security Officer, Massachussets Employment Security Commission.

3.1.3.2.2 Population. Of the 200 personnel stationed at Otis AFB because of PAVE PAWS, 100% of the military and 30% of the civilians will be new to the area. Assuming that 80% of the military and 90% of the civilians will be married, and assuming a family size of four (Etbauer, 1978), about 460 people will be arriving in Barnstable County.

As shown in Table 3-7, Cape Cod and the Upper Cape (Bourne, Falmouth, Mashpee, Sandwich, and Otis AFB) are both fast-growing areas. The influx of 460 people into the Cape will increase population in 1980 by less than 1% in both the county and the Upper Cape. The incoming population is equivalent to about 3 weeks of normal growth in the county, and 7 weeks of year-round population growth in the Upper Cape.

3.1.3.2.3 Income. Total personal income in Barnstable County will increase by about $4.7 million annually during the operation of PAVE PAWS. The change represents an increase of less than 1% of the regional income of $908 million in 1976.

3.1.3.2.4 Housing. It is expected that about 60 of the incoming military personnel will live on-base. The Air Force is in the process of rehabilitating 42 units on base, and an additional 30 units will be available from the Coast Guard, which has recently finished renovating 110 base units. Virtually all of the 72 units allocated to the Air Force are expected to be used by PAVE PAWS

personnel because the cost to the occupant of housing on-base is less than it is off-base. There are no quarters on-base for single military personnel; approximately 20 of those individuals will live off-base, as will about 20 married military personnel who will prefer to buy or rent off-base housing. All of the 100 civilians will live off-base, making a total of about 140 new Air Force personnel living off-base in Barnstable County.

Table 3-7

HISTORIC AND PROJECTED POPULATION CHANGE, 1975-1980

| Area | 1975[a] | 1977[a] | Projected 1980 Without Action[a] | Annual Average Percent Change 1975-1977 | Annual Average 1977-1980 Without AF Action | Annual Average 1977-1980 With AF Action |
|---|---|---|---|---|---|---|
| Upper Cape | 42,100[b] | 48,900[b] | 50,200 | 6.9 | 0.9 | 1.2 |
| Barnstable County | 128,000 | 142,200 | 146,000 | 5.0 | 0.9 | 1.0 |

[a]208 Plan.

[b]Includes Otis AFB.

It is anticipated that 90% of those living off-base -- about 130 people -- will live within the townships of Bourne, Sandwich, Falmouth, and Mashpee. Those areas are close to the base (Otis AFB is actually contained within the four townships) have available housing, and currently house most of the off-base personnel. The distribution of people is likely to be slightly different than in the past because the new northern entrance to the base is much closer to the PAVE PAWS facility than is the western entrance.

Approximately 70%, or 90 people, will live in the town of Bourne, which is close to the base and the northern entrance. Both of the entrances to Otis AFB are contained within the town of Bourne, and Bourne has a low average price of housing relative to the other three towns. It is estimated that around 30%, or 30 people, will live in the town of Sandwich, which is also close to

the base but has about half as many housing units as Bourne. The remaining 10 people are expected to live in the towns of Falmouth and Mashpee. No one is expected to buy a home in Mashpee because land titles there are clouded by a suit brought against the town by the Mashpee Indians, who claim legal ownership of the town. Settlement of the suit may take another year (Peters, 1978). Some new residents, however, may rent homes in Mashpee.

PAVE PAWS personnel would occupy less than 1% of the total housing units in Barnstable County, and less than 1% of the total housing units in the four affected townships, based on the Cape Cod Planning and Economic Development Commission's 1977 Annual Report, which implies that there were about 26,630 housing units in the four townships, and 91,100 housing units in the county as of 1977.

3.1.3.2.5 Education. Based on the current geographical distribution of personnel at Otis AFB, 69% of the new arrivals are projected to locate on the base or in Bourne, 29% in Sandwich, 2% in Falmouth, and fewer than 1% in Mashpee. The families moving into the area are expected to bring with them 380 school-aged children (Etbauer, 1978).

3.1.3.2.5.1 Bourne. Using these percentages, approximately 260 additional students are expected to enter the Bourne schools when PAVE PAWS becomes operational. The new pupils will represent an increase in enrollment of approximately 9.2%. Based on Bourne's average PL 874 grant in 1977-78 of $522 per federally-related child (an average of on- and off-base students), the school department should expect to receive about $135,700 in extra funds under PL 874. The grant would represent 2.4% of Bourne's 1978-79 school budget of more than $5.6 million.

The increase of 260 students in the Bourne School District might strain the already crowded Bourne schools. According to R. T. Brown, Superintendent of the district, it depends on what grades the incoming students will enter.

3.1.3.2.5.2 Sandwich. Schools in Sandwich are expected to receive 110 new students related to the PAVE PAWS project, making cramped conditions even more crowded. The elementary school is already over capacity by 50 students (see Section E.1.5.2, p. E-11), and school officials expect the number of students in the junior-senior high school to reach that institution's capacity by next fall, even without the children of the additional PAVE PAWS personnel. The influx of 110 pupils would increase the student population in Sandwich to 1,940, reflecting a growth of 6%.

Sandwich in 1977-78 received an average of $161.54 under PL 874 for every federally related child in the schools. Based on that figure, the school department should expect to receive roughly $17,770 in additional federal funds for the new pupils. The anticipated grant would represent 0.9% of the current school budget of $2 million.

3.1.3.2.5.3 <u>Mashpee</u>. Very few families coming to Cape Cod for the PAVE PAWS project are expected to locate in Mashpee. The litigation lodged by the Mashpee tribe stands as the principal reason (see Section 3.1.3.2.4). A few families might choose to rent housing in Mashpee, which would increase school enrollments slightly; however, school enrollments in Mashpee are not expected to change significantly as a result of the PAVE PAWS project.

3.1.3.2.5.4 <u>Falmouth</u>. Falmouth is expected to absorb 10 new pupils as a result of the PAVE PAWS project, increasing enrollment by an insignificant 0.2%. The school department expects to receive $63,000 in PL 874 funds this year for 366 federally related students, or an average of $172.13 per child. Based on that figure, the Falmouth schools could anticipate an extra $1,700 in Federal funds for the additional students. The grant would represent less than 0.02% of the school department's 1978-79 budget of $9,257,987.

3.1.3.2.6 <u>Health Care</u>. The additional PAVE PAWS workers and their dependents are not likely to put a strain on local health and hospital facilities (Howes, 1978). The increase of 460 people in Barnstable County will not significantly change the ratio of 1.6 physicians per thousand residents in the county.

3.1.3.2.7 <u>Tourism</u>. The operation of PAVE PAWS will likely have a negligible effect on tourism in Barnstable County.

### 3.1.4 <u>Growth System</u>

The considerations in Sections 3.1.2 and 3.1.3 (pp. 3-17 and 3-82) also apply to the growth system generally. In this section, we consider the growth system specifically, bringing together in one place a consideration of the effects anticipated should the basic system someday be expanded. Power densities for the growth system are presented in the same format used in Section 3.1.1 (p. 3-1) for the basic system. Then modifications of the expected biophysical and socioeconomic impacts are summarized.

### 3.1.4.1 Exposure to EMR in the Growth System

As for the case with the basic system, the main beam of the growth system is constrained from illuminating the vicinity of PAVE PAWS at and near ground level (below 300 ft MSL). But whereas the first sidelobe for the basic system increased the power density significantly at the higher elevations (up to 300 ft MSL, depending on range), the first sidelobe for the growth system does not increase the power density significantly at those elevations. The reason is that the first sidelobe, like the main beam, is focused into a narrower angle. At the minimum 3-deg elevation of the main beam, the small portion of the first sidelobe in the growth system that is radiated below the antenna center (at 320 ft MSL) is comparable in power density to the higher-order sidelobes. Consequently, the calculated power density for the growth system varies only with distance from the radar for any elevation up to 300 ft MSL.

Figure 3-16 shows power density at ground level for the growth system in the range 1,400-3,000 ft, which extends through most of the transition zone to the beginning of the far field (the comparable range is 1,000-1,500 ft in the basic system). The figure shows that the power densities at 1,400 ft in the growth system are comparable to the power densities at 1,000 ft (near the exclusion fence) in the basic system.

Figures 3-17 and 3-18 indicate the power density for the growth system in the ranges 3,000-7,000 ft and 7,000-25,000 ft, respectively. All three figures for the growth system can be used together with Figure 3-1 (p. 3-3) to estimate power density for elevations below 300 ft MSL.

With regard to sector 3 at close range (see Figure 3-9, p. 3-12), values for the growth system of 80 and 160 microwatts/cm$^2$ were calculated for the points of closest approach, outside the exclusion and security areas on the northwest (350 ft) and southwest (250 ft), respectively. These values compare with 42 and 90 microwatts/cm$^2$, respectively, for the basic system (see Table 3-1, p. 3-11).

A broad comparison of the growth system with the basic system exposures at ground level cannot be made both simple and accurate because of the irregular terrain near PAVE PAWS at Otis AFB and the variation of basic system exposure with elevation. Generally, it may be said that exposures from the growth system are from 1 to 2 times as high as exposures from the basic system at a given distance in the far field. Other characterizations of the relative power densities must rely on the detailed figures referenced above.

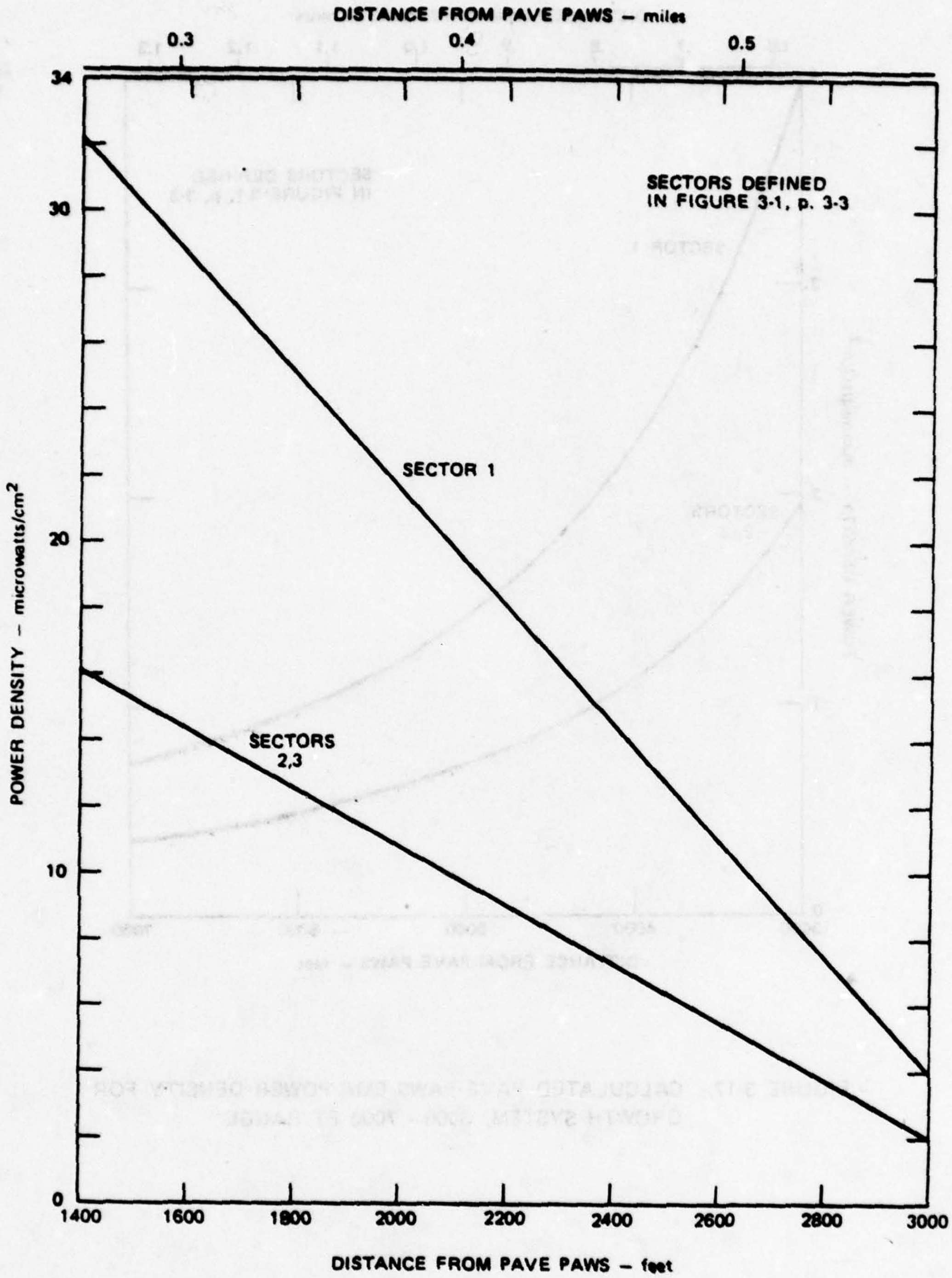


FIGURE 3-16. CALCULATED PAVE PAWS EMR POWER DENSITY FOR GROWTH SYSTEM, AT GROUND LEVEL, 1400-3000 FT RANGE

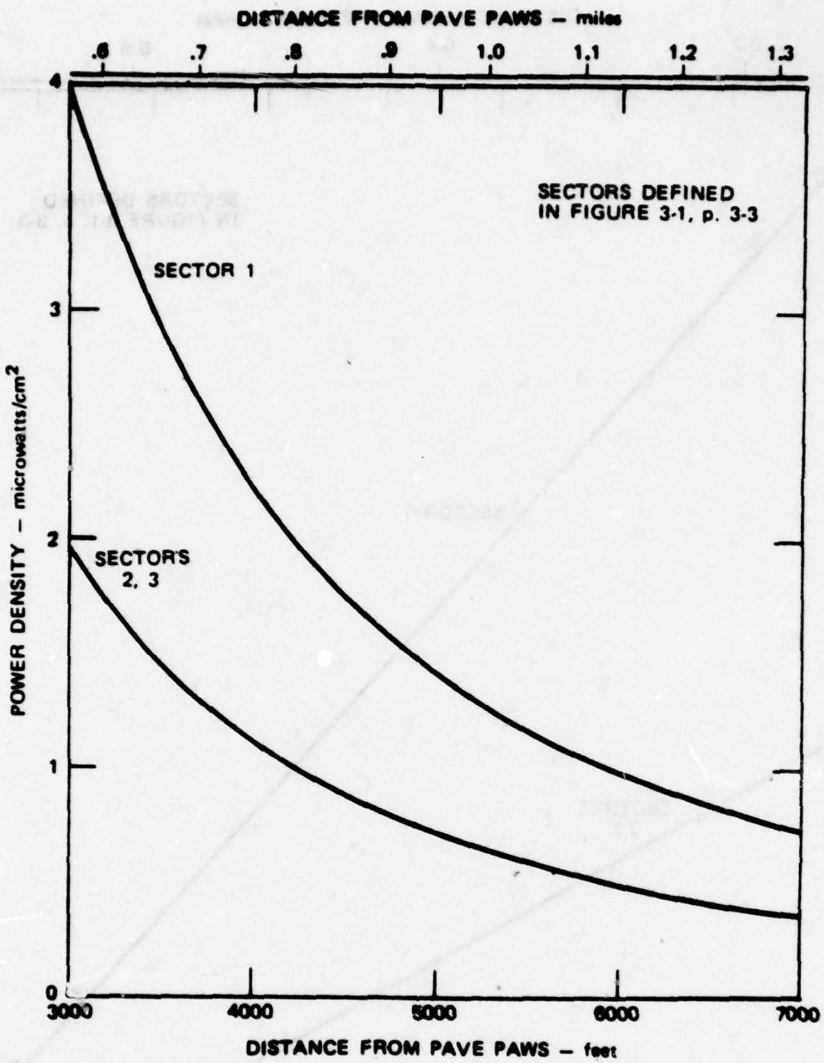


FIGURE 3-17. CALCULATED PAVE PAWS EMR POWER DENSITY FOR GROWTH SYSTEM, 3000 - 7000 FT RANGE

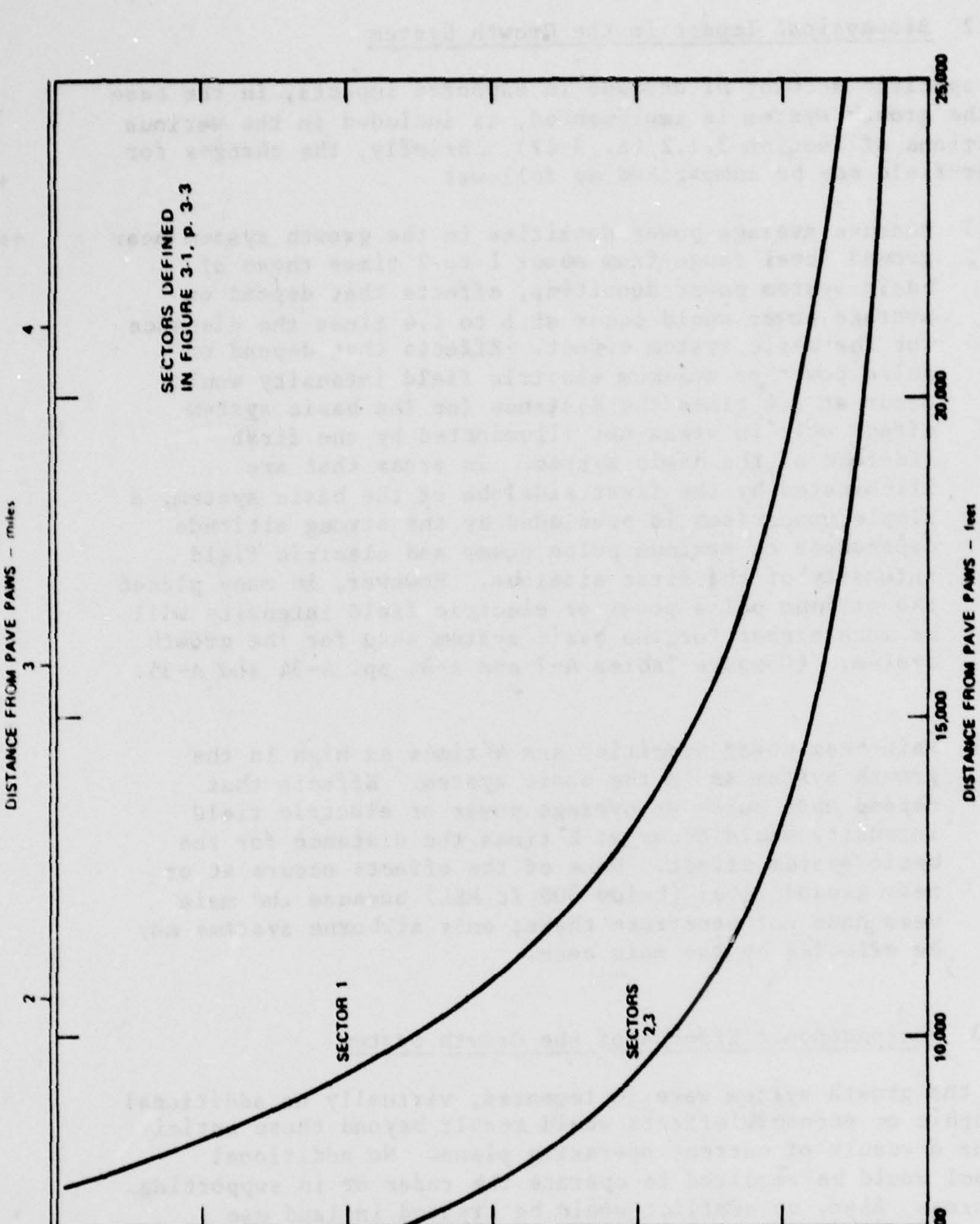


FIGURE 3-18. CALCULATED PAVE PAWS EMR POWER DENSITY FOR GROWTH SYSTEM, 7,000–25,000 FT RANGE

### 3.1.4.2 Biophysical Impact in the Growth System

A specific account of changes in expected impacts, in the case that the growth system is implemented, is included in the various subsections of Section 3.1.2 (p. 3-17). Briefly, the changes for the far-field may be summarized as follows: +

(1) Because average power densities in the growth system near ground level range from about 1 to 2 times those of basic-system power densities, effects that depend on average power would occur at 1 to 1.4 times the distance for the basic system effect. Effects that depend on pulse power or maximum electric field intensity would occur at 1.4 times the distance for the basic system effect only in areas not illuminated by the first sidelobe of the basic system. In areas that are illuminated by the first sidelobe of the basic system, a simple comparison is precluded by the strong altitude dependence of maximum pulse power and electric field intensity of the first sidelobe. However, in many places the maximum pulse power or electric field intensity will be much higher for the basic system than for the growth system. (Compare Tables A-7 and A-8, pp. A-34 and A-35. ++

+

(2) Main-beam power densities are 4 times as high in the growth system as in the basic system. Effects that depend upon pulse or average power or electric field intensity would occur at 2 times the distance for the basic system effect. None of the effects occurs at or near ground level (below 300 ft MSL) because the main beam does not penetrate there; only airborne systems may be affected by the main beam.

### 3.1.4.3 Socioeconomic Effects of the Growth System

If the growth system were implemented, virtually no additional demographic or economic effects would result beyond those anticipated as a result of current operating plans. No additional personnel would be required to operate the radar or in supporting activities. Also, no conflict would be created in land use between PAVE PAWS and the proposed Route 25 and Route 28 highway extension, which, as planned, would be placed no closer than 2,700 ft from the radar. +

## 3.2 Fort Fisher AFS, North Carolina

### 3.2.1 Biophysical Impacts

The potential biophysical effects of the discontinuation of Detachment 5 at Fort Fisher AFS are inconsequential.

### 3.2.2 Socioeconomic Impacts

#### 3.2.2.1 Land Use

There are plans to convert the present AN/FSS-7 radar tower at Fort Fisher to an AN/FPS-90 height-finder radar (Hess, 1978). The new height-finder will replace the AN/MPS-14 height-finder radar, which is currently operating at the base under the supervision of the 701st Radar Squadron.

The physical appearance of Fort Fisher will not change as a result of the conversion. The present radar tower was originally built as a height-finder, and so the tower, dome, and much of the other equipment connected with the radar can be re-used. The computer software and other components that cannot be used with the new height-finder will be shipped to a military supply base.

Authorized staffing of the new radar is projected to be the same as to operate the current height-finder.

#### 3.2.2.2 Demographics and Economics

3.2.2.2.1 Employment. Employment losses are estimated to be about 60 jobs at Fort Fisher (54 personnel assigned to Detachment 5, and between 1 and 3 additional positions currently filled by personnel from the 701st radar squadron), and about 10 jobs in the community held by dependents who will probably leave the area. Spending in the area that would theoretically support an additional 20 secondary jobs will be lost, but few of those jobs will actually be lost if the spending effects are spread out over many different employers.

Table E-9 (p. E-14) in Appendix E shows historic levels of employment and unemployment rates in the Wilmington SMSA. Since employment statistics consider only the civilian labor force, changes in military personnel would not show up in these figures. The impact of employment changes because of the Air Force action can be approximated using civilian labor force data. Employment between 1976 and 1977 increased unusually slowly, so a two-year average will be used to examine employment effects. The loss of about 70 jobs (assuming, as is likely, that no secondary jobs will be lost) is equal to the loss of about 1 month of employment growth, based on the 2-year county trend in the civilian labor force.

3.2.2.2.2 Population. Population in New Hanover County may decline by approximately 160 people when Detachment 5 leaves Fort Fisher. This figure reflects the consideration of the roughly 180 military and civilian personnel and their dependents connected

with Detachment 5, and the fact that some of those personnel may not leave the area (they may either retire or find other jobs).

Historic and projected population figures are shown in Table 3-8, and historic and projected average annual growth rates, with and without the Air Force action, are shown in Table 3-9. The growth rate with the closure of the Detachment 5 unit is 0.1% less than the growth rate without the closure in the year that the reduction is scheduled to take place. The loss of 160 people is the equivalent to the loss of about 2 months of population growth in the county.

3.2.2.2.3 Personal Income. New Hanover County may lose roughly $800,000 in total personal income from the loss of the 70 jobs. That represents a decline of less than 1% of total personal income in the county in 1976.

3.2.2.2.4 Housing. About 30 families currently living off-base will be leaving the area when Detachment 5 is closed down. Most of those families -- about 25 of them -- are renters who will be giving up rental houses or apartments in Wilmington. Thus, 25 rental units will be added to the approximately 500 available rental units (as of May 1978). A small number of those leaving -- about 5 -- own their houses. Thus, 5 houses could be added to the 350-450 homes usually on the market in Wilmington.

3.2.2.2.5 Education. About 40 school-aged children will be leaving the area when Detachment 5 closes operation. Most of them will be leaving the New Hanover County school district; a few will be leaving schools in adjacent Brunswick County. New Hanover County schools will lose about 30 students out of a total enrollment of 20,912 in September, 1978, or 0.1% of their total student enrollment. The loss of PL 874 funds, roughly $625 per military pupil, will amount to about $20,000 (Howie, 1978). Compared to the total school district budget of $30.8 million, the $20,000 loss represents a decline of less than 1%.

3.2.2.2.6 Health Care. The loss of about 160 people in New Hanover County will reduce the demand for services of local physicians and hospitals in the county. It is difficult to estimate how much Air Force personnel use the local health care facilities because most of the military personnel use the clinic at Fort Fisher for minor medical treatment, and Camp Lejeune in Inslow County (about 40 miles from Wilmington) for major problems.

Table 3-8

POPULATION CHANGE, WILMINGTON AND NEW HANOVER COUNTIES, 1970-1980

| County | 1970[a] | 1976[a] | Projected 1979 Without AF Action[b] | Projected 1980 Without AF Action | Projected 1980 With AF Action |
|---|---|---|---|---|---|
| Wilmington | 46,169 | 52,390 | NA[c] | 52,600 | NA[c] |
| New Hanover | 82,996 | 96,100 | 100,000 | 101,300 | 99,800 |

[a]Source: "Community Profile -- Greater Wilmington Area," Greater Wilmington Chamber of Commerce, 1978.

[b]Estimate from "Summary, Population and Economy, Wilmington and New Hanover County," Wilmington and New Hanover County Planning Department, no date.

[c]Not available.

Table 3-9

POPULATION GROWTH RATES, 1970-1979
(Percent)

| County | Average Annual Growth Rate, 1970-1976 | Average Annual Growth Rate, 1976-1979 Without AF Action | Average Annual Growth Rate, 1976-1979 With AF Action |
|---|---|---|---|
| Wilmington | 2.0 | NA[a] | NA[a] |
| New Hanover | 2.3 | 1.3 | 1.2 |

[a]Not available.

It can be assumed that most major military health problems are cared for at Camp Lejeune, because it is much less expensive for military personnel to use base facilities than to visit local physicians and hospitals.

The loss of the Air Force personnel and their families will not change the projected ratio of 1.5 physicians per thousand people in 1979. The loss of 2 civilian families and 20-30 military families who prefer to use the health care facilities in Wilmington will not change local use of physicians and hospitals appreciably.

## 3.3 Charleston AFS, Maine

### 3.3.1 Biophysical Impacts

The potential biophysical effects of the discontinuation of Detachment 6 at Charleston AFS are inconsequential.

### 3.3.2 Socioeconomics Impacts

#### 3.3.2.1 Land Use and Aesthetics

The current scheduled time to deactivate the entire Charleston AFS with PAVE PAWS operational is late 1979. The station would then become surplus property to be disposed of by the General Services Administration (GSA). Because GSA is expected to take several years to remove some of the technical equipment at the station and thus not sell the land and other facilities until about 1981, local officials have already indicated their intention to mobilize before then to develop definite plans for immediate use of the station. They believe that negative consequences (economic and otherwise) could result from the land and the structures on it being vacant for a long time.

The Eastern Maine Development District has identified several potential uses for Charleston AFS including: a light manufacturing complex, a communications transmission facility, a post-secondary vocational educational center for the forest trades, a youth training center, and a minimum security detention center (A Preliminary Assessment of Potential Impacts Resulting from Major Military Reductions at the Charleston and Bucks Harbor Air Force Stations, 1978).

#### 3.3.2.2 Demographics and Economics

3.3.2.2.1 Employment. Employment losses are estimated to be 45 primary jobs at Charleston AFB and 10 secondary jobs held by dependents who will leave the area. Spending in the area suffi-

cient to support an additional 10 jobs will be lost, but it is likely that spending losses will be spread out over many different employers so that no current employees will become unemployed.

Employment in Penobscot County has been declining in recent years because many small and medium-size firms have closed. Many people have also left the area, so the unemployment rate in the county actually declined from 8.8% in 1975 to 8.2% in 1977 (see Section E.3.1, p. E-17).

Employment between 1976 and 1977 declined by 600, for an average annual growth rate of -1.0%. Comparison with civilian labor force data shows that a loss of between 55 to 60 jobs would be the equivalent of about 5 weeks of historical employment decline.

3.3.2.2.2 Population. Population in Penobscot County may decline by about 110 people when Detachment 6 leaves Charleston AFS. About 130 military and civilian personnel and their dependents are connected with Detachment 6, and about 20 of them may not be leaving the county (because they may either retire or find other jobs).

Population figures for Bangor and Penobscot County, with and without the Air Force action, are shown in Table 3-10. Table 3-11 shows that the growth rate for the county is not expected to change because of the Air Force action. The loss of 110 people is equivalent to the loss of about 6 weeks of population growth.

3.3.2.2.3 Personal Income. Penobscot County will lose roughly $600,000 in total personal income as a resut of the loss of approximately sixty jobs. Compared to personal income in 1976, this represents a decline of less than 1%.

3.3.2.2.4 Housing. Most of the Detachment 6 personnel live on base either at Charleston or at Dow. Four families own homes off-base, and one family rents housing off-base. If all of these families left the area, it would add 4 vacant houses and 1 vacant apartment in a county that had a housing stock of about 50,000 in 1975 (Penobscot Valley Regional Planning Commission, no date).

3.3.2.2.5 Education. About 35 school-age children will be leaving local schools when Detachment 6 leaves Charleston. About 30 of these students will be leaving the Bangor School District, which had a total enrollment of 5,221 students in September 1978. This 30-student loss is less than 1% of total enrollment in the district.

The PL 874 fund entitlement for fiscal year 1978 is $168,166, or about $448 per federally related student. Thus, the district will lose about $13,400, less than 1% of the total school budget of $8.8 million, if these 30 students leave.

3.3.2.2.6 Health Care. The loss of 110 people in Penobscot County will somewhat reduce the demand for the services of local physicians and hospitals. Military personnel use the base clinic for minor medical problems, but they use local facilities for many major problems because the closest military facility for handling critical medical needs is about 200 miles from Charleston AFS.

All of the hospitals in Bangor have high occupancy rates -- more than 73%, for all but the osteopathic hospital -- and should be little affected by the loss of 110 people.

Table 3-10

POPULATION CHANGE, BANGOR AND PENOBSCOT COUNTY, 1970-1980

| Area | 1970[a] | 1977[a] | Projected 1978[b] | Projected 1980 Without AF Action[a] | Projected 1980 With AF Action |
|---|---|---|---|---|---|
| Bangor | 33,168 | 32,740 | 33,910 | 33,290 | NA[c] |
| Penobscot County | 124,482 | 136,030 | 138,475 | 140,380 | 140,270 |

[a] Source: "Provisional Municipal Population Projections," Maine State Planning Office (December 1977).

[b] Source: Projections provided by Lawrence Berkeley Laboratory and Regional Office of Employment and Training Projections, provided to the U.S. Department of Labor (1977).

[c] Not available.

Table 3-11

POPULATION GROWTH RATES, 1970-1980
(Percent)

| Area | Average Annual Growth Rate, 1970-1980 | Average Annual Growth Rate, 1977-1980 Without AF Action | Average Annual Rate, 1977-1980 With AF Action |
|---|---|---|---|
| Bangor | 0.3 | 0.6 | NA[a] |
| Penobscot County | 1.7 | 1.0 | 1.0 |

[a]Not available.

# Chapter 4

# ALTERNATIVES

In this chapter, four possible alternatives to the proposed action (i.e., operation of the PAVE PAWS radar facility on Flatrock Hill at Otis AFB) will be considered. They are:

- o Not to operate PAVE PAWS
- o Postpone full-scale operation of PAVE PAWS
- o Move the radar to one of three possible alternative locations
- o Modify the radar or its surroundings.

Each of the alternatives is described in the paragraphs that follow.

## 4.1 No Action

The no-action alternative is not to operate the PAVE PAWS facility at Otis AFB. All the impacts of construction have already been experienced. Therefore, only the effects of operation can be avoided if this alternative is pursued.

Not operating PAVE PAWS also means foregoing the benefits to national security and defense to be gained by its operation. If PAVE PAWS is not operated, operation of radars that it is scheduled to replace will continue. However, those radars have been outdated by technical advances in surveillance and tracking radars, and by evolution in the nature of the threat from sea-launched ballistic missiles. Specifically, the PAVE PAWS radar, based on the phased-array technology, can track many targets concurrently (as opposed to being dedicated to only a single target at a time), can do so more accurately and at 3,000 nautical miles range (as opposed to a range of less than 1,000 miles). In addition, it can simultaneously search for objects as well as track objects, thus permitting detection and accurate counting of all attacking sea-launched ballistic missiles. It is this superior ability to warn and to characterize missile attacks that would be sacrificed if PAVE PAWS were not operated.

No alternative methods of radar surveillance and tracking other than continued operation of obsolete radars are available in the foreseeable future if PAVE PAWS is not operated. Consequently, it is possible that changes in defensive military strategies would be necessary if information characterizing an attack (which PAVE PAWS would provide) were not available.

## 4.2 Postpone Action

This alternative would involve postponing full-scale operation of PAVE PAWS. Neither the characteristics of PAVE PAWS operation nor the affected characteristics of the environment would change with the passage of time. Therefore, postponement would only delay occurrence of the impacts discussed in Chapter 3, and not alter them.

However, there is no apparent environmental benefit to be gained by postponement. Even in the absence of complete and detailed knowledge of biological effects, the information now available does not indicate any significant risk and is being used to provide safeguards, such as exclusions.

On the other hand, given the real threat posed by sea-launched ballistic missiles, a lengthy postponement would increase the risk to the security of the U.S. Radars now in operation are incapable of adequately characterizing a sea-launched ballistic missile attack and providing ample warning time to strategic forces. Existing Soviet missiles can overfly the present radars, thereby avoiding detection. The resulting gap in warning capability allows the possibility of a surprise attack.

## 4.3 Different Locations

The original site selection process for the East Coast PAVE PAWS radar facility took approximately 18 months. Initially, ten potential locations for the radar were identified and then tested against a set of siting criteria. Each proposed site had to satisfy the first five criteria as a minimum requirement before it would be given further consideration. The basic siting criteria used were:

(1) Choice of real estate in descending order of priority: DOD property, other federal property, state and municipal property, and privately owned property.

(2) Operational requirements for coverage dictate a location within 150-mile radius of Greater Boston Area.

(3) Must have unobstructed line-of-sight view for 240 deg in azimuth (347 deg to 227 deg easterly) and for 2 deg or less above the horizon.

(4) Consider safe radiation hazard distances for people.

(5) Consider safe distances for persons wearing cardiac pacemakers.

(6) Consider fuel and ordnance hazards.

(7) Consider possible electromagnetic interference (EMI) to nearby military and civilian electronics installation and to home entertainment devices.

(8) Proximity to airfields, approach patterns, and restrictions to aircraft flying near the site.

(9) Availability of access roads, commercial power, water supply, sewage disposal, communications systems, housing, transportation, schools, churches, recreational, and other support facilities.

(10) Cost of site preparation.

After screening, three sites were still viewed as candidates: Westover AFB, Otis AFB, and North Truro AFS, all in Massachusetts. In the final selection process, Westover AFB was eliminated from further consideration for several reasons, including its proximity to a population center. North Truro was also excluded for several reasons, one of which was its proximity to the Cape Cod National Seashore. Finally, a comprehensive analysis conducted of Otis AFB indicated that the site was appropriate for the PAVE PAWS radar.

Within Otis, three potential sites (Pine Hill, Deer Horn Hill, and Hill 280) were evaluated prior to the selection of Flatrock Hill as the location for the radar. The other three sites were eliminated for the following reasons:

- Pine Hill--Location of PAVE PAWS at this site was opposed by the Massachusetts Army National Guard, and might have interferred with final flight approaches on Runway 14 at the Otis Airfield.

- Deer Horn Hill--The site was considered to be too close to base housing and might have conflicted with the siting of a proposed Veterans Administration cemetery.

- Hill 280--Construction and operation would have conflicted with National Guard activities to a greater degree than at other sites and would have involved the relocation of a 115-kV commercial power transmission line.

After the screening process had been completed, a formal environmental assessment made, and a negative determination decided, construction proceeded at Flatrock Hill. Nevertheless, it would still be feasible, although costly, to relocate the facility elsewhere.

Therefore, to address reasonable options in this study, two of the previous prospective sites and a new siting option will be examined as alternatives to the proposed action. (The relative instability of ships and airplanes makes them operationally unacceptable for a PAVE PAWS.) Because the radar facility is already in place, choosing another location at this point would necessitate dismantling the nearly completed radar and its support buildings, transport of the major pieces of the radar structure to the new site, and reconstruction of the radar as well as construction of ancillary buildings at a new location. The three alternative sites (see Figure 4-1) meeting operational criteria (see Section 4.3, p. 4-2) considered below are:

- o Pine Hill (also within Otis AFB)
- o A site at North Truro AFS (farther out on the Cape Cod peninsula)
- o A shoreline platform that extends out into the ocean away from the coast.

During 1977 some general assumptions were prepared relating to the termination of activities at the existing PAVE PAWS site and estimating the cost of relocation of the radar facility (J. Thornton, 1978). The assumptions regarding relocation then were:

- o All production and procurement activities will continue.
- o Critical hardware will be put in temporary storage.
- o All hardware will be retested after storage.
- o Termination costs will be paid to current construction subcontractors
- o New construction contracts will be awarded.
- o Relocation would delay the schedule by 33 months (including all construction and start-up activities).

The principal cost estimates still applicable for relocation, which are in 1977 dollars and do not include additional expenditures made since 1977, are presented in Table 4-1.

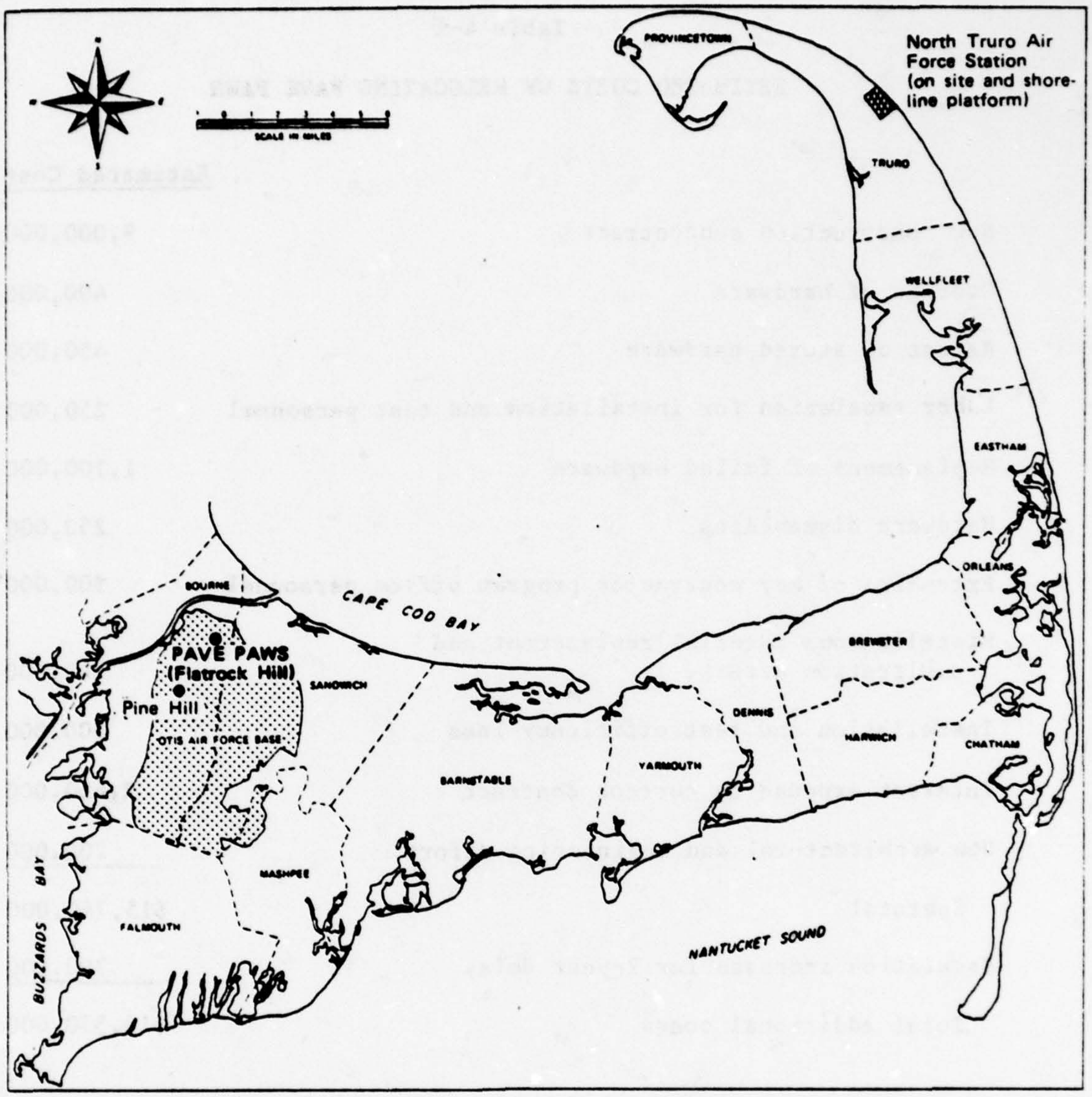


FIGURE 4-1. ALTERNATIVE LOCATIONS FOR PAVE PAWS

Table 4-1

ESTIMATED COSTS OF RELOCATING PAVE PAWS

| | Estimated Cost |
|---|---|
| New construction subcontract | 9,000,000 |
| Storage of hardware | 400,000 |
| Retest of stored hardware | 450,000 |
| Labor escalation for installation and test personnel | 250,000 |
| Replacement of failed hardware | 1,100,000 |
| Hardware dismantling | 250,000 |
| Extension of key contractor program office personnel | 900,000 |
| Miscellaneous material replacement and publication effort | 240,000 |
| Installation and test efficiency loss | 300,000 |
| Interest expense on current contract | 2,650,000 |
| New architectural and engineering effort | 200,000 |
| Subtotal | $15,740,000 |
| Escalation increase for 2-year delay | 790,000 |
| Total additional costs | $16,530,000 |

### 4.3.1 Pine Hill, Otis AFB, Massachusetts

#### 4.3.1.1 Existing Site Characteristics

Pine Hill is a radar communications site southeast of Flatrock Hill that is currently used by the Army National Guard for artillery firing exercises. Fifteen gun positions are situated on the Pine Hill site. Two towers, several buildings, and a mobile radar unit that is used for National Guard training purposes are located on Pine Hill, which is connected to the main portion of the base by a paved, two-lane, north-south road. In addition, a number of dirt roads in the vicinity of Pine Hill connect portions of the National Guard's firing range. Table 4-2 compares the distances from Flatrock Hill and Pine Hill to important locations both within and outside Otis AFB.

The soils, geology, and existing water resources of the Pine Hill site are similar to Flatrock Hill. The top of Pine Hill reaches an elevation of 306 feet -- the highest point on Cape Cod. The surrounding area is a gently rolling, irregular upland formed on the Buzzards Bay Moraine (Strahler, 1972). Unlike Flatrock Hill, no boulders are present at the site; rather, cobbles and rocks less than one foot in diameter occur at infrequent intervals on the surface of the sandy soil. As at Flatrock Hill, Plymouth soils limit intensive land use. Surface water drainage is poorly developed and characterized by ponds, wetlands, and a lack of defined stream channels. Pine Hill borders the major groundwater recharge area for the western Cape and the groundwater level at the site is approximately 250 feet below the land surface (LeBlanc and Guswa, 1977). The level is slightly deeper than at Flatrock Hill because of increased elevation at the site. Although a small well now exists, it is not a major water supply source. Groundwater quality at Otis AFB is generally excellent.

The vegetation of the Pine Hill site is quite similar to that in the vicinity of the radar at Flatrock Hill, apart from differences in apparent age. The trees are smaller, and the incidence of bear oak, an indicator of high fire frequency, is greater. The deer population is possibly larger than at the north Otis site, but no unusual habitats appear to be present at either location.

#### 4.3.1.2 Probable Impact of the Proposed Action on the Environment

Relocation of the PAVE PAWS facility to Pine Hill would require the dismantling of all existing buildings at Pine Hill, dismantling of the radar hardware now in place at Flatrock Hill, and, of course, reconstruction of the radar on Pine Hill.

The following probable impacts were the bases for rejecting Pine Hill as the site for PAVE PAWS:

Table 4-2

**APPROXIMATE LINEAR DISTANCES[a] FROM POPULATED AREAS TO PINE HILL AND FLATROCK HILL**

| Populated Area (Nearest Edge) | Distance to Pine Hill (miles) | Distance to Flatrock Hill (miles) |
|---|---|---|
| Nearest off-base residential area | 1.7 | 1.1 |
| Nearest on-base residential area | 2.9 | 6.3 |
| Extended Runway #14/32 | 3.1 | 5.9 |
| Route 6 (Mid-Cape Highway) | 3.8 | 0.7 |
| Route 28 | 1.0 | 2.6 |
| Route 25 (proposed extension) | 2.9 | 1.5 |
| Sagamore | 4.6 | 1.1 |
| Sandwich | 4.3 | 1.1 |
| Mashpee | 5.9 | 7.6 |
| Falmouth | 9.1 | 12.5 |
| Sagamore Bridge | 4.8 | 1.6 |
| Bourne Bridge | 3.0 | 2.7 |
| Sandwich Power Plant | 5.0 | 1.9 |
| Crane Wildlife Management area | 6.3 | 9.3 |

[a]Linear distances obtained from U.S. Geological Survey 7½-minute topographic maps of the area.

- A major relocation of and reduction in Massachusetts Army National Guard artillery firing positions would be required, access to the northern portion of the firing range would be restricted, and interference with the flight corridor used by range observation aircraft would have resulted.

- Interference with flight activities on one runway (#14) at the Otis AFB airfield would have occurred.

In addition to these probable impacts, other consequences have been considered, as described below.

Figure 4-2 shows the vicinity of Pine Hill with an exposure grid superimposed, analogous to Figure 3-1 (p. 3-3) for the Flatrock Hill site. Because the center of the antenna at Pine Hill would be about 40 feet higher than at Flatrock Hill, Figures 3-3 through 3-8 (pp. 3-5 through 3-10), 3-17, and 3-18 (pp. 3-96 and 3-97) may be used to estimate exposures in the vicinity of Pine Hill with the following adjustment. From any elevation of interest at Pine Hill below about 340 feet, subtract 40 feet. The resultant adjusted elevation (together with the appropriate distance) and Figures 3-3 through 3-6 then may be used to obtain the exposure estimate for Pine Hill. Use of Figures 3-7 and 3-8, as well as Figures 3-17 and 3-18 for the growth system, does not require an elevation. Qualitatively, it is clear that the Pine Hill site is more remote from population centers than Flatrock Hill, and would result in lower overall exposure to RFR.

In other respects, such as kind of effects expected and degree of interference or hazard at specified exposures to RFR from PAVE PAWS, conclusions in Chapter 3 and the appendices regarding the Flatrock Hill site apply also to the Pine Hill site.

No significant erosion is expected to result from the construction and operation of PAVE PAWS on Pine Hill. Although the soil is less rocky than at Flatrock Hill, its excessive permeability and sufficiently varied character make it unsusceptible to erosion. Cleared areas nearby show no indication of incipient erosion.

The construction and operation of PAVE PAWS on Pine Hill would not significantly affect the water resources. Because the area has abundant groundwater reserves, the rate of use would cause minimal drawdown. The nearest surface water body, Succonessett Pond, is one mile to the east and is not connected to the site by any surface water channel. In fact, there are no defined stream channels in the vicinity -- the existing ponds are isolated depressions formed by past glacial activity. Assuming the construction of PAVE PAWS at this site would entail safeguards for diesel handling and storage similar to those already employed at Flatrock

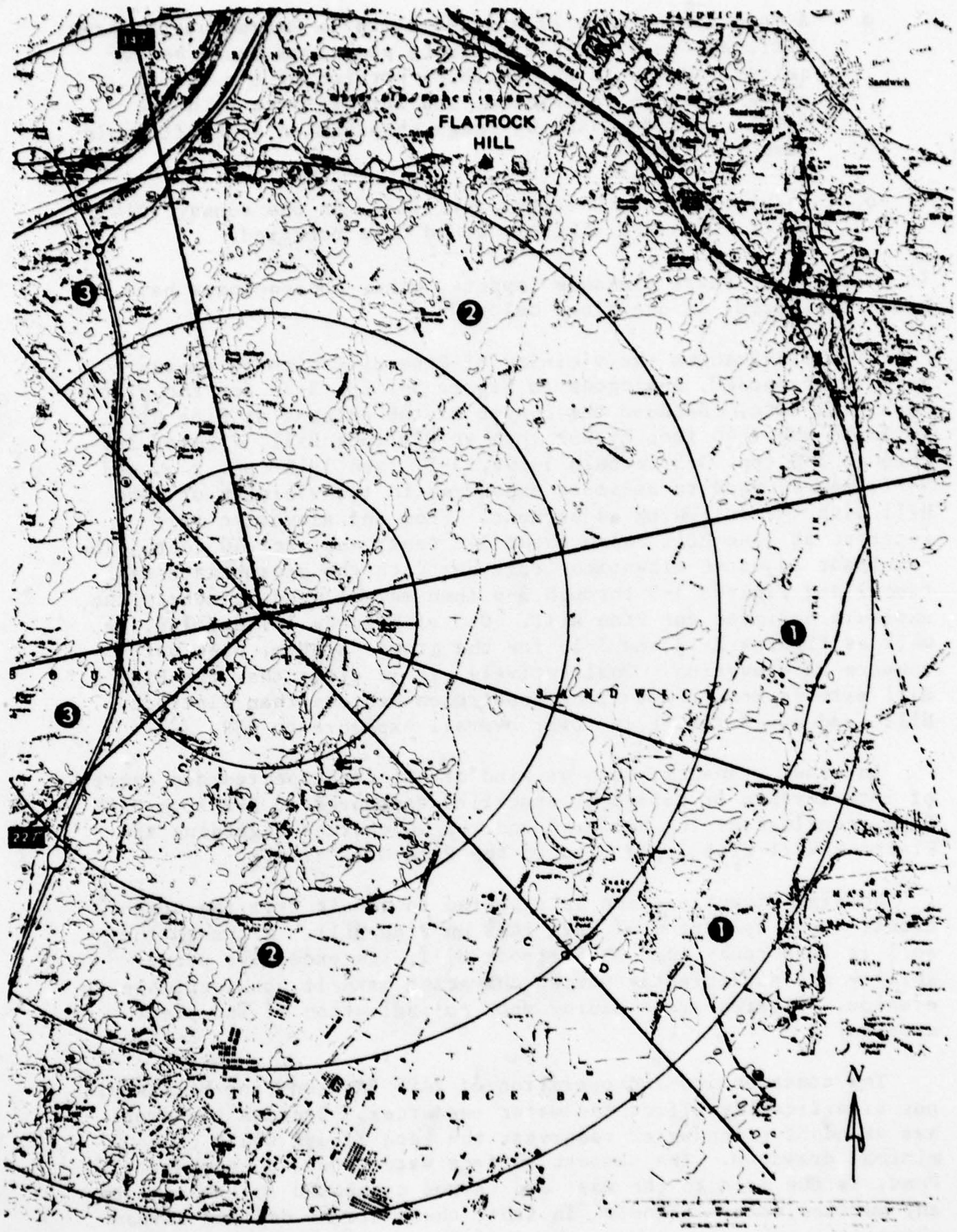


FIGURE 4-2. PAVE PAWS AZIMUTH FROM THE PINE HILL ALTERNATIVE

Hill, the potential for aquifer contamination at the site is similarly minimal.

Noise levels from construction and operation of PAVE PAWS at Pine Hill would be greater than at Flatrock Hill for two reasons: the distance from the radar to areas of public access is less at Pine Hill, and the dismantling of current facilities at Flatrock Hill and Pine Hill and reinstallation of the PAVE PAWS equipment at Pine Hill would create additional disturbance. The closest public areas at Pine Hill are along MacArthur Boulevard (Route 28), a minimum distance of approximately 5,000 feet. At that distance the noise level from the cooling tower would be 12 dB, which is barely audible, and from the power generators, less than 40 dB. As with Route 6 and Flatrock Hill, the PAVE PAWS noise levels would be masked by the noise of the highway traffic.

Effects on air quality from operating PAVE PAWS on Pine Hill will be virtually identical to those that would result from its operation on Flatrock Hill. However, the construction that would be necessary to prepare Pine Hill and the movement of the equipment installed on Flatrock Hill would result in noticeable but temporary increases in dust and pollutants from construction equipment and related traffic.

If PAVE PAWS were moved to Pine Hill, the visible impact on its surroundings would be very similar to the impact on Flatrock Hill now, except that the primary areas from which PAVE PAWS is visible would be the Bourne Bridge and villages in Bourne, such as Pocasset and Monument Beach. In contrast, PAVE PAWS is visible now mainly from the Sagamore Bridge and parts of Sandwich.

The socioeconomic effects of radar operation at Pine Hill would be almost identical to those cited for the proposed action at Flatrock Hill. There would be approximately 200 military and civilian personnel involved in daily operational activities; some would live on-base in renovated housing and others would presumably reside in existing housing in nearby communities. The only anticipated difference would be in the distribution of housing; as access to Pine Hill would be through a different entrance at Otis AFB, more of the radar personnel (than assumed for Flatrock Hill) might choose to reside in the towns of Falmouth and Mashpee and fewer in Bourne and Sandwich.

### 4.3.2 North Truro AFS, Massachusetts

#### 4.3.2.1 Existing Site Characteristics

North Truro AFS, located near the tip of Cape Cod, is within the boundary of the town of Truro, yet is surrounded by Cape Cod National Seashore land. Over one half of the Station's 100 acres

comprises the working and housing area. This central area of the Station includes:

- One large and one small well
- Commissary store
- Hobby shop
- Power plant with five diesel generators (two operate at a time, 24 hours a day).
- Steam heating plant
- Heliport
- Sewage plant and leach field
- Recreation buildings
- Operations and supply buildings
- Housing units.

In addition, three currently operating radar structures are at North Truro AFS. The storage tanks for gasoline are located underground and those for diesel fuel have been installed above ground. Both water and steam are distributed through the main station area in supply lines or pipes placed 8 feet over the ground surface to prevent the pipes from freezing in winter. The North Truro Station is currently supplying 500,000 gallons per day of water to Provincetown.

The North Truro site is located on the gently rolling, sandy uplands forming the top of an 150-foot-high, wave-cut bluff. The North Truro AFS lies on the North Truro Outwash Plain, an unstratified deposit of sand, silt, and gravel formed during the waning stages of the Wisconsin glaciation (Strahler, 1972). The deep, excessively drained Carver soils that have developed on this geologic material severely limit farming because of droughtiness and limit on-site sewage disposal because of rapid permeability (Cape Cod Planning and Economic Development Commission, 1978). Erosion is of some concern in the area; the entire bluff from Eastman Beach to Highland Beach is currently being eroded at a rate of 5 acres per year (U.S. Geological Survey, 1976). The aquifer is undergoing some drawdown because of increasing land development (and associated increased water use) in the Provincetown area. In addition, because a portion of the aquifer has been contaminated by leaking underground gasoline tanks in Provincetown, emergency water supplies are being piped from the North Truro AFS and the Cape Cod National Seashore.

The North Truro site is covered by plants that are characteristic of stabilized sand dunes and are quite sensitive to construction activities. These vegetations tolerate dry, infertile sandy soils, but are easily damaged by vehicular traffic. Rapid and severe erosion of the sand typically follows such destruction, resulting in features known as "blowouts", which may cover several acres on terrain similar to that at North Truro.

The North Truro site has recreational potential because it is near the protected Cape Cod National Seashore. In addition, the site provides habitat for migrating waterfowl, although it is too small to support other large transient animals or significant numbers of resident wildlife.

Currently, 150 military and civilian persons reside at North Truro, 145 of whom are employed on-base. Due to personnel reductions in recent years, there is a surplus of housing and other facilities at North Truro.

Medical needs of personnel at the station are attended to by two independent medical technicians and two local physicians employed by the Air Force as part-time civil service employees. Medical services are provided in the Base's Medical Aid Station.

No formal fire department is situated on the Base although a single fire truck is parked there in case of emergency.

Outside the North Truro AFS, a few private residences and a camping area/trailer park are located ¼ mile from the Station on National Seashore land. The village of North Truro is not far from the Station and the Central School is 1 mile to the south. The closest hospital to the Station is in Hyannis; the A.I.M. Outpatient Clinic is in Wellfleet, 10-15 miles away.

The town of North Truro had an 87% increase in population between 1950 and 1970. In 1970, North Truro had the lowest population in Barnstable County -- 1,234 people -- and a population density of 46 people per square mile. As of 1971, 8% of the land area in North Truro was urban residential land (as compared with 1% two decades earlier), 14% was agricultural and open land, 1% was commercial land, 3% was used for recreation, and 62% was forest. As of 1975, 1,300 acres had been developed, 2,800 were considered buildable, and 9,000 were set aside for open space.

During 1975, the summer population of Truro was approximately 11,900, while the winter population was estimated at 1,440, of whom 380 were children enrolled in the town's school. In that year, there were approximately 1,300 housing units in Truro; 850 units (64%) were used as second homes. Nearly all year-round units (approximately 450) were occupied in 1975. During 1977, the labor force of the town averaged 474 persons, and the average

unemployment rate for the year was 5.5% (ranging from 3.4% during July to 9.6% in January).

### 4.3.2.2 Probable Impact of the Proposed Action on the Environment

The following probable impacts were the bases for rejecting the North Truro site for PAVE PAWS:

- The risk of violating environmental objectives was thought to be high because of North Truro's proximity to Cape Cod National Seashore.
- North Truro is farther from a support base than other alternative sites.
- Power facilities would have to be expanded to accommodate activities associated with the radar facility.
- A minimum amount of land area (50 acres) and configuration to satisfy radar facility requirements is not available.

In addition to these probable impacts, other consequences have been considered, as described below.

Figure 4-3 shows the vicinity of North Truro with an exposure grid superimposed, analogous to Figure 3-1 (p. 3-3) for the Flatrock Hill site. Because the center of the antenna at North Truro would be about 120 feet lower than at Flatrock Hill, Figures 3-3 through 3-8 (pp. 3-5 through 3-10), 3-17, and 3-18 (pp. 3-96 and 3-97), may be used to estimate exposures in the vicinity of North Truro with the following adjustment. To any elevation of interest at North Truro below about 180 ft, add 120 ft. The resultant adjusted elevation (together with the appropriate distance) and Figures 3-3 through 3-6 then may be used to obtain the exposure estimate for North Truro. Use of Figures 3-7 and 3-8, as well as Figures 3-17 and 3-18 for the growth system, does not require an elevation. Qualitatively, the North Truro site is more remote from population centers than Flatrock Hill, and would result in lower overall exposure to RFR. However, some existing housing is much closer to the radar at North Truro.

In other respects, such as kind of effects expected and degree of interference or hazard at specified exposures to RFR from PAVE PAWS, conclusions in Chapter 3 and the appendices regarding the Flatrock Hill site apply also to the North Truro site.

Because the North Truro site is upgradient in the aquifer from Provincetown, potential aquifer contamination at that location is a concern. The Cape Cod Planning and Economic Development Commission has indicated that the Commission would carefully


FIGURE 4-3. PAVE PAWS AZIMUTH FROM THE NORTH TRURO ALTERNATIVE

review any proposal for development at North Truro (Daniels and Magnuson, 1978).

The disruption entailed with construction of a facility as large as the PAVE PAWS radar could destabilize sandy soil at the North Truro site so as to cause abrasion hazards for the radar elements and significant erosion, which could threaten the integrity of the radar facility if measures were not taken to stabilize the surrounding soil. Substantial damage might be sustained by the building itself; during a hurricane or a series of winter storms, wind erosion could result in the undermining of structural foundations.

The site identified as the most likely location on the Base for the radar facility itself is a paved, level, and approximately 2-acre area used as a helipad. The prepared site would only accommodate the radar structure; disruption of additional land would be necessary for the construction of access roads, petroleum and water storage facilities, leaching areas and the power plant associated with PAVE PAWS. The land that would have to be prepared for the ancillary facilities is uneven, rolling terrain.

As with the Pine Hill alternative, noise levels would increase during construction and during subsequent operation at North Truro. However, PAVE PAWS would have to be located closer to the Air Force property boundaries than at the other sites because of the relatively small area of the Air Force Station. Recreationalists on the National Seashore directly adjacent to the base might be adversely affected by PAVE PAWS noise to the extent that it is not masked by noise from the ocean. Operation-related air pollutants would be emitted in North Truro at the same rate as they are on Flatrock Hill. Moving the facility would cause a temporary increase in air pollutants that would be generated during earth moving and use of construction equipment.

The PAVE PAWS radar building is approximately twice as high as the radomes now at the North Truro AFS. If PAVE PAWS were moved to North Truro, the 105-ft high radar building would most likely be visible from the Mid-Cape highway and residential areas for several miles both northwest toward Provincetown, and south toward Wellfleet. However, the topography of the beach cliffs would probably prevent the radar building from being visible from the beach below. PAVE PAWS would be clearly visible from boats in the Atlantic off the Cape, and would possibly be visible from boats in Cape Cod Bay.

The importance of the natural landscape in the toe of the Cape is evident from the amount of land devoted to the Cape Cod National Seashore and the amount of economic activity related to tourists in the area. A building such as PAVE PAWS would most likely be considered an adverse impact on the visual quality for which that area of the Cape is valued.

Both construction and operation of the PAVE PAWS facility at North Truro AFS would result in additional employment and population within and beyond the base. Construction activities would require approximately two years, during which the Base and the surrounding community would be temporarily affected.

During construction, workers would either have to commute to the construction site or be housed in temporary facilities nearby, for example, in excess base housing or in transient housing in the Truro area. Construction workers who would relocate to the site would generate additional spending and would require additional public services (such as medical care).

Approximately 200 persons (the same number of personnel estimated for Flatrock Hill) are expected to be required to operate the radar at North Truro. Most of these workers will either have to commute from other locations on the Cape or move to the North Truro area because of the extremely small local labor force. If 70 secondary jobs are also created, as estimated for the proposed action at Otis, most of these will also have to be filled by commuters or new residents. Thus, the total number of new jobs associated with PAVE PAWS at North Truro is expected to be around 250. Assuming the majority of employees would be married and assuming an average family size of four, the current population (approximately 1500) would increase by over 50%. Such an increase would certainly affect all conditions in the town of Truro -- income, housing (although some on-base housing could probably be made available), and the school, in particular. The consequences to the county as a whole would not be as noticeable as to the local area.

### 4.3.3 Shoreline Platform

The third alternative for relocating PAVE PAWS has been designated the shoreline platform alternative. A platform for the radar situated on a pier-like structure extending into the ocean from the coast would represent a compromise between a site on land and an offshore platform.

Siting the radar at sea on a platform similar to those which supported Texas Tower radars in the 1950s and 1960s could conceivably reduce the exposure of people and systems to the RFR. However, the support and service requirements (e.g., helicopters, supply boats, etc.) for such an arrangement are complicated and costly, and offshore platforms are susceptible to being damaged in turbulent weather despite built-in precautions. Consequently, the compromise shoreline platform was selected as an alternative to achieve in part the remoteness of an offshore platform while mitigating the security, logistics, and support problems. Because the platform would have to be designed to withstand fairly severe

winter storms, it would be more costly to construct than the other location options.

In principle, a shoreline platform could be placed at any number of locations along the coast in the Cape Cod area, assuming approval could be obtained from various regulatory authorities. However, one possible site for a long pier and radar platform might be below the bluff at North Truro AFS, if the National Park Service would approve access from the national seashore. Support activities for the radar facility could then be provided, as for the North Truro option, as part of base operations. Necessary ancillary buildings might be placed atop the bluff on the former helipad also considered for use as part of the North Truro alternative.

The visual impact of PAVE PAWS on a platform would be somewhat different than for PAVE PAWS at the North Truro AFS. The major difference would be the visibility of the radar from the beach areas of the Cape Cod National Seashore. Because of operational constraints, the height of the platform would put the PAVE PAWS at an elevation similar to the onshore alternative (about 150 ft above mean sea level). Thus, the areas onshore from which PAVE PAWS would be visible would be substantially the same as with the North Truro alternative. Relative to the aesthetic impact of the North Truro alternative, the visual intrusion of the platform and radar would be more severe.

The socioeconomic consequences of construction and operation of the shoreline platform in the location proposed would be comparable to those described for the North Truro option.

Figure 4-4 shows the vicinity of the platform off North Truro with an exposure grid superimposed, analogous to Figure 3-1 (p. 3-3) for the Flatrock Hill site. Because the center of the antenna on the platform would be about 120 feet lower than at Flatrock Hill, Figures 3-3 through 3-8 (pp. 3-5 through 3-10), 3-17, and 3-18 (pp. 3-96 and 3-97) may be used to estimate exposures in the vicinity of the platform with the following adjustment. To any elevation of interest at North Truro below about 180 ft, add 120 ft. The resultant adjusted elevation (together with the appropriate distance) and Figures 3-3 through 3-6 then may be used to obtain the exposure estimate for the platform alternative. Use of Figures 3-7 and 3-8, as well as Figures 3-17 and 3-18 for the growth system, does not require an elevation. Qualitatively, the shoreline platform site is more remote from population centers than Flatrock Hill, and would result in lower overall exposure to RFR. The lack of control over approach within 1,000 ft of the radar by sea is mitigated by the higher elevation (about 150 ft) of the radar and, hence, its near field.

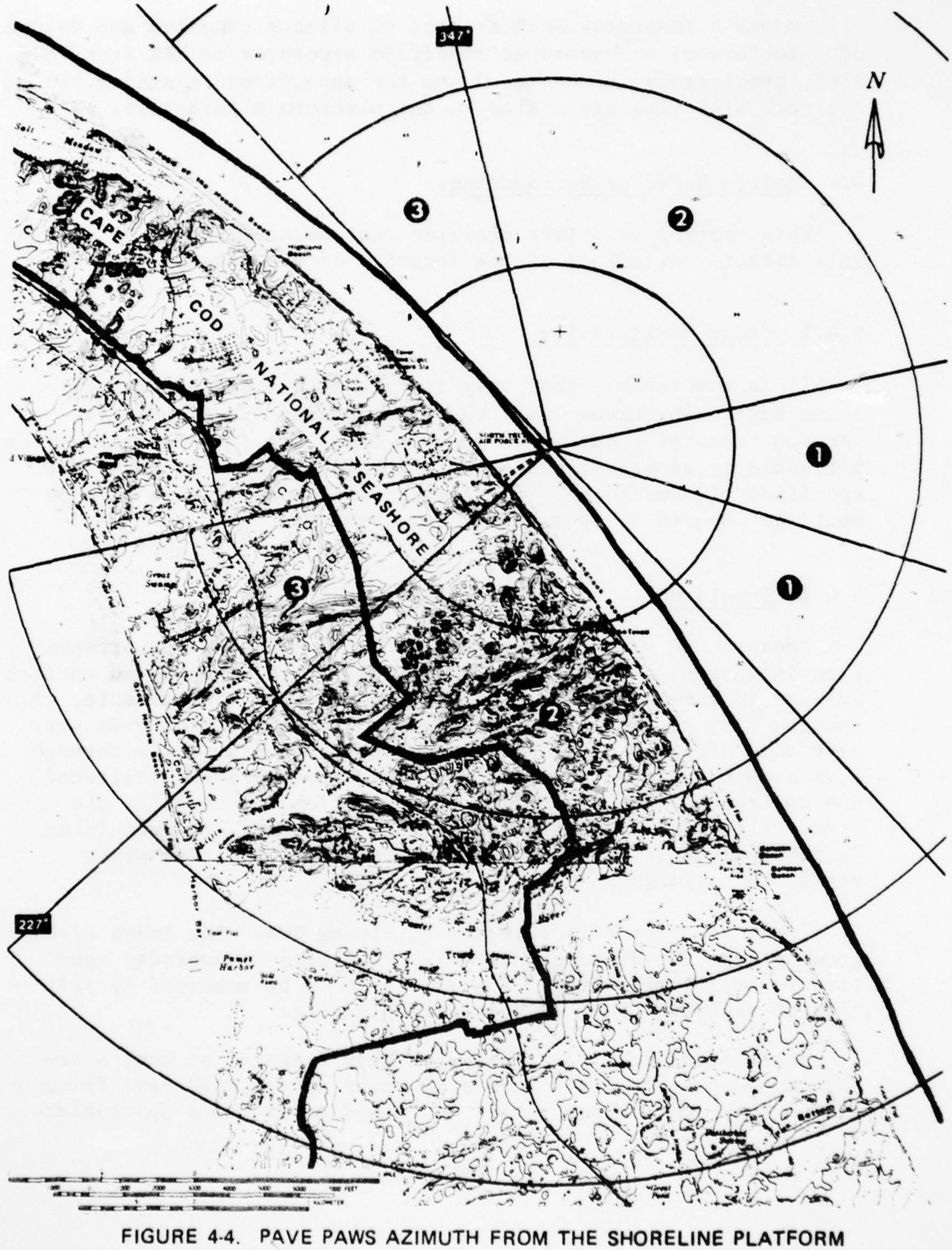


FIGURE 4-4. PAVE PAWS AZIMUTH FROM THE SHORELINE PLATFORM ALTERNATIVE

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ENVIRONMENTAL IMPACT STATEMENT - OPERATION OF THE PAVE PAWS RAD--ETC(U)
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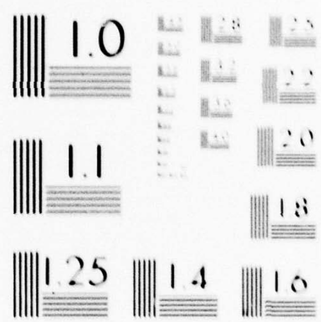
AD A069200




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

In other respects, such as kind of effects expected and degree of interference or hazard at specified exposures to RFR from PAVE PAWS, conclusions in Chapter 3 and the appendices regarding the Flatrock Hill site apply also to the platform alternative.

### 4.4 Modify Radar or Surroundings

This section describes measures that might be taken to ameliorate effects regardless of the location of the antenna.

#### 4.4.1 Radar Modification

It is conceivable that only certain frequencies or surveillance fence elevations would cause interference, and only for certain times or locations. In this case, the interference may be mitigated by suppressing the use of those frequencies under the specified circumstances. The limits on the use of this measure would be imposed by operational requirements.

#### 4.4.2 Shielding

Because the earth absorbs and reflects EMR, and the attenuation is very high at the frequencies used by PAVE PAWS, an earthen barrier is a very effective shield against EMR. For example, an earthen berm placed close to the subject area would provide the best shielding. The power that would penetrate directly through such a berm would be negligible compared to the power scattered and diffracted into the region shadowed from the radar by the berm. Based on the concept of optical shadowing, the shielding factor available in this manner should exceed 10:1 and might easily be as large as 100:1.

Trees are also effective for shielding EMR. The trees already growing near the Flatrock Hill PAVE PAWS site undoubtedly contribute useful shielding. The effect could be enhanced by addition of suitable trees at appropriate places.

Sheet metal or wire screen with mesh sizes of at most a few inches are effective reflectors of power at the PAVE PAWS frequencies. They could also be used to shield areas where appropriate.

## Chapter 5

## PROBABLE ADVERSE ENVIRONMENTAL EFFECTS WHICH CANNOT BE AVOIDED SHOULD THE PROPOSAL BE IMPLEMENTED

### 5.1 Land Use

Only minor land use effects are anticipated. A small amount of land (about 10 acres) has been committed to permanent structures. Another 50 acres has been fenced off to exclude people and some animals from the near field of the radar. These 50 acres are part of a 3,000-acre wildlife management area. The 50 acres could be returned to their prior use as a wildlife habitat when operation of PAVE PAWS ends. However, it is possible that the permanent PAVE PAWS structures will not be removed at that time, and 10 acres of wildlife habitat may be lost indefinitely.

### 5.2 Population and Economics

The expected demographic and economic effects of PAVE PAWS are also minor. Small changes in the working and civilian population in the vicinity of Otis AFB, Fort Fisher AFS, and Charleston AFS are expected. However, these changes will be very small compared with historical changes in these areas and therefore will not be significant, whether they are viewed as beneficial or as adverse.

### 5.3 Electromagnetic Interference

Some interference with TV reception, certain military aircraft radar altimeters, aircraft mobile and ham radios, and other radar equipment in the area is predicted. In most cases this interference should not be disruptive; in others, it could be reduced by adjustments to the equipment or possibly by changes in the operation of the PAVE PAWS radar.

PAVE PAWS operation could affect cardiac pacemakers. However, units worn by people on the ground are very unlikely to be affected outside the exclusion zone, which was defined, in part, by consideration of the susceptibility of pacemakers to EMR. To bring an aircraft carrying a pacemaker owner into the part of the PAVE PAWS surveillance volume where the pacemaker could be affected requires ignoring basic flight safety rules limiting low-level flight. Moreover, even with low level penetration of

that shallow volume, the duration of exposure would not exceed a few seconds.

## 5.4 Human Health

To assess the potential effects of EMR on human health, an extensive review of research literature was undertaken. The results indicate that human health could be affected by EMR from PAVE PAWS at distances very close to the antenna array. However, the potentially hazardous region is within the exclusion fence. Thus, avoidance of hazard to human health depends on maintaining the integrity of the exclusion fence.

## Chapter 6

## RELATIONSHIP BETWEEN LOCAL SHORT-TERM USE OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

Operation of PAVE PAWS will be a local and short-term use of the environment. PAVE PAWS will enhance the security of the United States over its operational lifetime. In exchange for this benefit, permanent structures will be built on a small amount of land (10 acres), and another 50 acres will be temporarily unavailable to a wildlife management area.

During the useful life of PAVE PAWS, large mammals will be denied access to the 50 acres, but the natural features of the area will not otherwise be disturbed. However, PAVE PAWS operation will affect only a small part of the entire wildlife management area, and thus will probably cause only a very small reduction in the short-term productivity of the local environment. Furthermore, the 50 acres can easily be returned later to use as a habitat for wildlife. The permanent structures can also be removed to return the remaining 10 acres to wildlife use. Consequently, the inevitable reduction in long-term productivity of the environment is small at most.

An inevitable accompaniment of PAVE PAWS will be interference with telecommunications systems and other devices. Much of the potential interference will not be very disruptive or can be mitigated to some degree. However, interference will cease when operation of PAVE PAWS is discontinued. Therefore, no long-term loss of productivity will result.

Operating PAVE PAWS will require shifting manpower requirements -- fewer at two other AFSs, more at Otis AFB. The short-term effects of the losses and gains will not be significant overall. The long-run effects will be hardly noticeable.

Although PAVE PAWS will have local, short-term effects on the use of the environment and its productivity, no significant short- or long-term losses of productivity are expected. In particular, future options for use of the site will not be restricted.

## Chapter 7

## IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES THAT WOULD BE INVOLVED IN THE PROPOSED ACTION SHOULD IT BE IMPLEMENTED

Operation of PAVE PAWS will involve the use of land, money, materials, and energy. Once put to use, all of these resources, except land, are irreversibly and irretrievably committed. This includes the fuel used to generate 2.5 megawatts of operating + power, although the energy required for PAVE PAWS does not represent a totally new commitment if allowance is made for the 500 kW of power saved by deactivating the two FSS-7 radars that + PAVE PAWS will replace. The money required to pay employees and to purchase materials and services to operate the facility will be similarly offset. Materials to build the facility have been irretrievably committed, unless recovery of resources from solid wastes begins to be practiced on a larger scale. Energy efficient + construction methods and material were used in compliance with + federal guidelines. +

The PAVE PAWS facility occupies about 4 acres of land including a parking area, a gate house, fuel storage, and utilities. Another 6 acres are required for the access road. Permanent structures are constructed only on these 10 acres. However, even these structures could be removed, and the relatively small area could be restored to its previous condition or one so close to it that it could again serve as a wildlife habitat.

Operation of PAVE PAWS will also require fencing off approximately 50 acres to prevent humans and large animals from coming too close to the radar. However, the land that will be occupied or fenced off during PAVE PAWS operation will not be irreversibly and irretrievably committed.

## Chapter 8

## CONSIDERATIONS THAT OFFSET THE ADVERSE ENVIRONMENTAL EFFECTS

As described in the previous sections, the environmental effects of operating PAVE PAWS are either insignificant or can be reduced to acceptable levels. Therefore, the benefits of operating PAVE PAWS can be obtained at little cost to the environment.

The environmental effects tend to be offset by the substantially improved sea-launched ballistic missile detection and tracking capability that will be provided by PAVE PAWS. In view of the real threat posed by more sophisticated sea-launched ballistic missiles, the PAVE PAWS capability, which is more advanced than the radars it will supercede, is essential to maintaining the security of the United States. PAVE PAWS is needed to characterize a sea-launched ballistic missile attack adequately and to provide warnings to strategic forces.

All the alternatives discussed in Chapter 4 except choosing not to operate the radar (e.g., no action) would provide the same benefits as those expected from operating PAVE PAWS at Flatrock Hill. On the other hand, of the alternatives described in Chapter 4, only taking no action would result in significantly fewer environmental effects. In fact, additional adverse effects would be created by abandoning (or dismantling) the existing facility and constructing a new one, and the benefits would be significantly delayed while a new facility is constructed. The necessity for new construction makes all the alternatives except no action equivalent to postponing the action. Thus, all of the alternatives to the proposed action except no action would delay the benefits of PAVE PAWS and increase its adverse environmental effects. Furthermore, the no action alternative, although it would avoid all adverse effects, would deliver no benefits.

## Chapter 9

## DETAILS OF UNRESOLVED ISSUES

### 9.1 Biological Effects

The potential biological effects of RFR from the PAVE PAWS facility have been assessed out of necessity from existing studies in the 10 MHz to 18 GHz range. The conclusion is that the RFR will have no perceptible biological effects on the human population in the vicinity of PAVE PAWS. The fundamental bases for this conclusion are the substantial evidence for dependence of many reported effects on exogenous heat production in the biological material; the considerable difference between the power densities in the neighborhood of PAVE PAWS and those lowest power densities at which a few biological effects have been reported -- amounting in most cases to between 2 and 4 orders of magnitude; and the absence of reliable evidence of objective human disease in persons exposed to RFR in the past. The substantial weight of these considerations allows the conclusion of absence of bioeffects from the RFR of PAVE PAWS without considering the two gaps in knowledge of the extrapolation of experimental results from animals to humans and the adequacy of epidemiological studies in humans.

The extrapolation of experimental results from one frequency to another and from one animal species was discussed briefly in Section C.4, p. C-9. Some progress has been made in the development of theoretical models for extrapolating from one frequency to another (as discussed in Section C.6.1.1, p. C-16) but the present level of knowledge is inadequate for predicting precisely the biological effects of RFR in humans from studies performed in mice or other experimental animals.

The existing epidemiological studies were reviewed in Section C.7.1, p. C-27. The studies were competently performed, but they are all retrospective in nature, i.e., undertaken after the occurrence of RFR exposure, and they suffer from certain inherent defects of retrospective studies, such as uncertainty about the level and duration of exposure, possible selective factors in locating members of the exposed population, and the difficulty in constructing adequate control groups. Prospective studies, in which the exposed population is identified before exposure begins, would eliminate such defects and provide a better basis for conclusions about effects of RFR on human health.

These two issues, extrapolation and epidemiology, remain unresolved issues in the assessment of bioeffects of RFR, though they do not affect the conclusions reached in this EIS. These issues are presently receiving considerable attention at the federal level.

## 9.2 Electromagnetic Interference

### 9.2.1 Telecommunication Systems ++

Further operating experience is necessary to determine the extent, if any, of the following potential interference situations:

- Television reception
- Airborne electronics

### 9.2.2 Other Devices

There is almost no possibility of effects on pacemakers which meet the 200 V/m susceptibility criterion. Pacemakers now being made generally do meet that standard. However, a complete assessment requires an answer to the question:

- What is the present distribution of the susceptibility thresholds of the pacemaker population, and what will it be in the near future?

## 9.3 Litigation

A lawsuit, Civil Action N. 78-533-T, was filed in the U.S. District Court for the District of Massachusetts. Briefly, the lawsuit alleged that the Air Force was required to prepare an EIS and asked for an injunction suspending activities at the PAVE PAWS site until the EIS was prepared. The continuing exchange of information by and between the Air Force, local residents and the plaintiffs, as well as the anticipated public involvement in and evaluation of this environmental study, caused the parties to conclude that further litigation of the matters raised in the complaint would be premature and that such litigation may ultimately be unnecessary. On 3 November 1978 Judge Tauro approved a stipulation which suspends the litigation until completion of this EIS (U.S. District Court, 1978b).

## Chapter 10

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## Appendix A

## RADAR AND ANTENNA CHARACTERISTICS

### A.1 Introduction

This appendix describes the principal characteristics of the PAVE PAWS radar system and the analytical procedure used to calculate the electric field intensities and time-averaged power densities that will result from its electromagnetic radiation (EMR). To avoid repetition in this appendix the term field strength is used as a general term to mean both power density and electric field intensity. Known characteristics of the radar system and proven analytical techniques are used to establish a model of the EMR field distribution. Based on this model, probable values of the time-averaged power densities and electric field intensities are calculated for points of interest near ground level at various locations and elevations in the vicinity of the PAVE PAWS site. Power densities at the center of the beam are also calculated to provide a basis for estimating their effect on the personnel and electronic systems in aircraft and on migratory birds.

This analytic technique allows predictions that are quite accurate in free space. However, the results are affected by the presence of the ground and of objects such as trees, buildings, and power lines. In the real world the ground terrain is irregular and any objects, such as trees, buildings, or other structures, are randomly distributed. When they block the line of sight to the antenna, they tend to absorb, reflect, and scatter the field. In such circumstances, the strength of the field is lower than it would be in free space. In other situations the power reflected from the earth or other objects adds to that propagated directly, thus increasing the intensity of the radiation. Under circumstances relevant to PAVE PAWS, the electric field strength is rarely as much as doubled in this way. Field enhancement of this kind is much more important in calculations of maximum electric field strengths than of time-averaged power densities.

### A.2 System Characteristics

#### A.2.1 System Parameters

The characteristics of the PAVE PAWS radar used in this analysis were obtained from the PAVE PAWS Program Office, Hanscom Air

Force Base, Massachusetts (Etkind, 1978). These characteristics are listed in Table A-1. The basic system has been installed; the growth system represents a possible option to upgrade the performance of the system at some future date.

The primary function of this radar is to detect sea-launched missiles at very great distances. To perform this function the radar must radiate a very strong, well-focused, beam of electromagnetic energy and must provide a corresponding sophistication in receiving any echo that is returned from a distant missile. These considerations force the system designer to use a very large antenna and provide a strong motivation to refine the design so that most of the power is concentrated in the main beam. The PAVE PAWS antenna meets these criteria, concentrating about 60% of the available power in the main beam (Etkind, 1978b).

A general idea of the beam forming process is provided by Figure A-1 (p. A-4). Near the antenna face the energy moves forward in a circular column of roughly constant diameter. At a greater distance it expands as a cone with an included angle of 5.2 deg and with its apex at the center of the antenna face. A slender conical beam of this kind is commonly referred to as a pencil beam. The intersection of the cone and cylinder occurs at a distance of about $0.33\ D^2/L$, where D is the active array diameter and L is the radiation wavelength. A more detailed description of the beam is provided in following sections.

### A.2.2 Antenna Scanning Characteristics

To carry out its tasks, the pencil beam formed by the antenna is scanned continuously. Using a complex time-sharing technique, the radar generates a surveillance fence (scan) at a minimum elevation of 3 deg above horizontal and covering 240 deg in azimuth, and executes special satellite searches, and numerous target tracks, all within as short a time as 44 s. This great versatility + is made possible by the electronic beam scanning characteristics of the phased array, which can change beam locations from any direction in the coverage volume to any other direction within + tens of microseconds. (To perform their basic functions radar + systems operate in very brief units of time. The conventional unit is the microsecond, i.e., one-millionth of a second; it is to be distinguished from the millisecond, which is one-thousand times longer.) In the present context, the major effect of beam scanning is to reduce the time-averaged power density.

### A.2.3 Antenna Scanning Limits

The PAVE PAWS antenna system is designed to prevent the transmitted beam from being directed below a minimum elevation angle or in any other direction outside its normal angular coverage. The minimum allowed elevation angle is 3 deg; redundant automatic

Table A-1

CHARACTERISTICS OF PAVE PAWS SYSTEM AT OTIS AFB

| System Characteristic | Basic System | Growth System |
|---|---|---|
| Frequency (MHz) | 420-450 | 420-450 |
| Peak power[a] (kW) | 582.4 | 1164.8 |
| Duty cycle (%) | | |
| Scan mode average | 11[b] | 11[b] |
| Track mode max (average) | 14 (7) | 14 (7) |
| Total max (average) | 25 (18) | 25 (18) |
| Active array diameter (ft) | 72.5 | 102 |
| Antenna gain (ratio) compared to non-directional antenna at 420 MHz | 6,200 | 12,300 |
| Beam width at half power density (deg) | 2.2 | 1.5 |
| Main beam null (deg off-axis) | 2.6 | 1.8 |
| First sidelobe -- max (deg off-axis) | 3.4 | 2.4 |
| First sidelobe relative power density -- max (ratio) | 0.01 | 0.01 |
| First sidelobe null (deg off-axis) | 4.8 | 3.3 |
| Secondary sidelobe maximum power density -- relative to main beam (ratio) | 0.001 | 0.001 |
| Secondary sidelobe average power density -- relative to main beam (ratio) | 0.00016 | 0.00008 |
| Angle of antenna face relative to vertical (deg) | 20 | 20 |
| Minimum elevation angle of beam (deg) | +3 | +3 |
| Scan sector (deg), (north = 360 deg, east = 90 deg, etc.) | 347 to 227 | 347 to 227 |

[a] Consistent with other sections of this document, we refer to the root-mean-square (rms) value of the pulse when present.

[b] Representative long-term value.

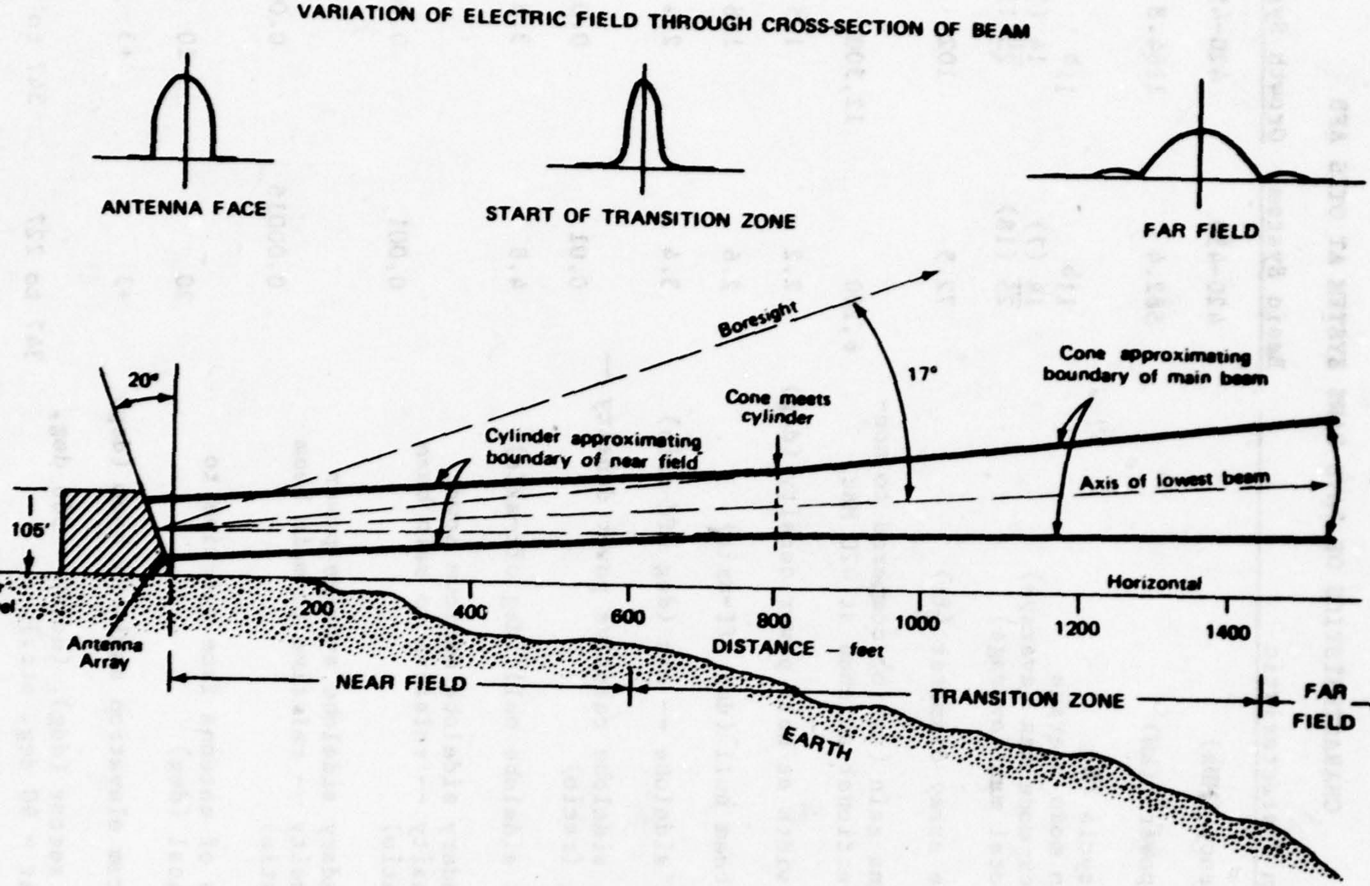


FIGURE A-1. FORMATION OF PAVE PAWS RADAR BEAM, BASIC SYSTEM

interlocks are provided to inhibit transmission of power in the improbable event of some system failure that might attempt to direct the beam outside the normal coverage defined by +3 deg to +85 deg elevation and ±60 deg azimuth on either face. These interlocks are contained in the Tactical Software, the Radar Control Computer Software, and in the Beam Steering Unit hardware.

Simultaneous failure of two software units and of the hardware interlocks would be required to direct the beam outside the approved coverage. The Tactical Software Interlock checks all radar commands before they leave the central computer. If a beam position outside the coverage volume were commanded, the command would be changed to stop transmission of the pulse. Beam directing commands are passed from the central computer to the Radar Control Computer where they are translated into commands that control individual elements of the radar hardware. Command sequences are checked to assure that the beam does not stop scanning for more than 16 consecutive pulses, and test commands from the Radar Control Computer Console are checked to assure that they are legitimate.

One of the hardware units controlled by the Radar Control Computer is the Beam Steering Unit. On a pulse-by-pulse basis this unit feeds the beam steering commands to the radar array (transmit/receive antenna) and controls on-off and transmit-receive switching. Each set of beam steering commands is checked in a hardware arithmetic unit for consistency to assure that they will direct the beam inside the coverage volume. If an illegal command is received, the transmitter is turned off so that the illegal pulse is not transmitted. In effect, two safety checks are built into the computer program plus a final check implemented in hardware.

This combination of design features and interlocks provides a design that would require simultaneous failure of at least three parts of the system in order to transmit a single pulse outside the intended radar coverage. The probability of such an occurrence is extremely low (NAS, 1979); no statistical base exists for developing a numerical value. +

### A.2.4 Antenna Grating Lobes

If the antenna element spacing exceeds half a wavelength in a phased array such as PAVE PAWS, additional lobes (known as grating lobes) can appear in the antenna radiation pattern. They are formed by the radiation from the elements adding in phase and forming additional wavefronts in directions for which the relative path lengths are integral multiples of one wavelength. When circumstances permit, grating lobes first form parallel to the array face (i.e., at 90 deg from the boresight direction) at the highest operating frequency of the radar, and when the main beam

is at the maximum scan angle. Unless suppressed in some way, the intensity of the grating lobes could be equal to that of the main beam. In any practical phased array system the element spacing is chosen to prevent grating lobes from forming.

For a phased array with the equilateral triangular element distribution used by PAVE PAWS, the maximum scan angle for a radiation pattern free of grating lobes is given by the following expression for a generally horizontal scan:

$$S_m = \arc \sin \left(\frac{L}{d \cos 30 \text{ deg}} - 1\right) \quad \text{(Kahrillos, 1976)}$$ +

where $S_m$ = maximum scan angle from array normal (deg).

$d$ = interelement spacing = 40.85 (cm)

$L$ = radiation wavelength at 450 MHz = 66.7 (cm)

Evaluating this expression gives a maximum scan angle from the array normal of 62.5 deg. As the maximum azimuth scan angle is 60 deg, no grating lobes will be formed.

Similar analyses have been performed for other scan directions to verify that grating lobes will not be formed for any scan direction. For example, the PAVE PAWS system must scan upward through 65 deg to reach the elevation of +85 deg. However, the governing equation for vertical scanning is

$$S_m = \arc \sin \left(\frac{L}{d/2} - 1\right) .$$

This equation is not satisfied by any real angle; therefore grating lobes cannot form in vertical scanning. +
+

A.2.5 Antenna Subarrays

An important advantage of phased array radar systems is that several of the elements can fail without seriously degrading the overall performance. An undesirable consequence of this feature is that considerable vigilance is required to detect and correct failure or malfunction of the individual elements.

The design of the PAVE PAWS radar includes diagnostic subsystems to solve this problem. Each face of the array is divided into 56 subarrays; each subarray consists of 32 transmitting/receiving elements and is capable of forming a beam; however, the resulting beams are necessarily much broader and less intense than those of the complete array. The disposition of the subarrays is shown in Figure A-2.

About 200 feet in front of each face and about 12 feet above local ground level a test antenna is located, which consists of a

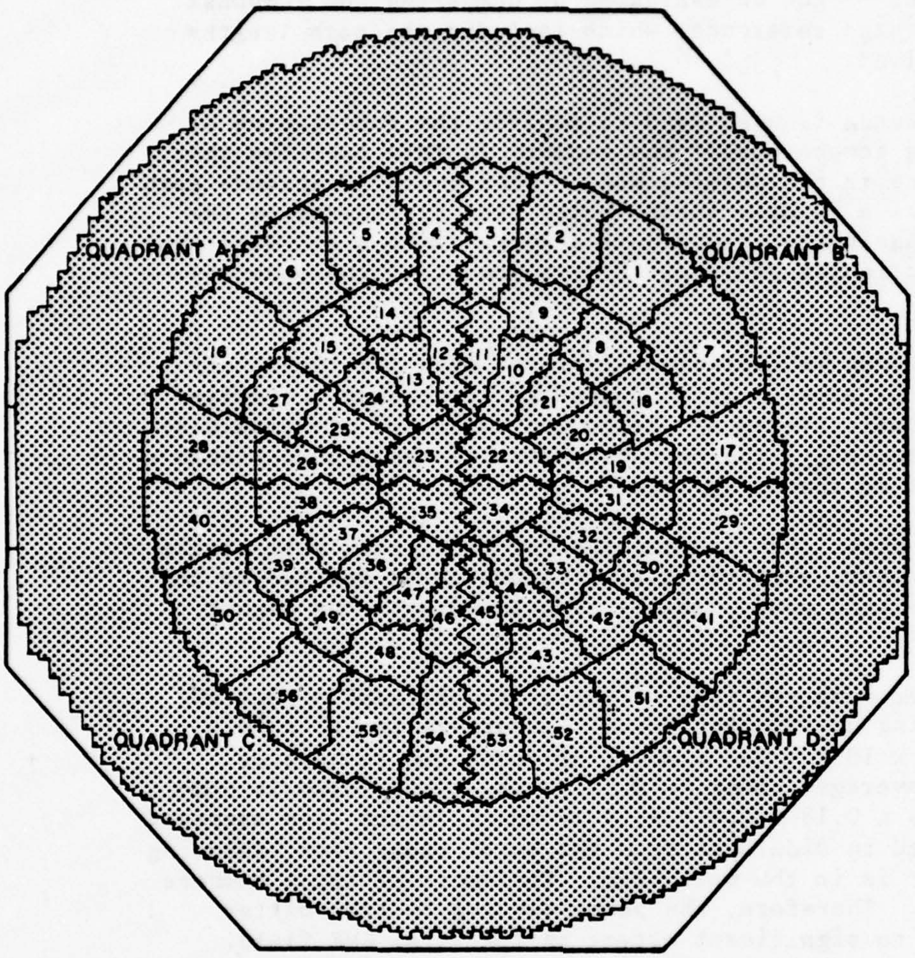


FIGURE A-2. SUBARRAY POSITIONS

standard crossed dipole element mounted on a circular metal disk about 3 feet in diameter. This antenna is connected through coaxial cables to monitoring equipment housed in the radar building; it is capable of both transmitting and receiving.

The receiving capabilities of the radar are tested by occasionally sending pulses of 50 microseconds duration from the test antenna. The receiving capability of any single element -- or group of elements -- can be evaluated by comparing the response with a precalibrated reference, which includes the path lengths and angles involved.

The test antenna is also used to monitor the functioning of the transmitting components of the radar. In this case the test antenna functions in a receiving mode. Once every 30 seconds each subarray delivers a 50 microsecond pulse that is focused on the test antenna. Again the response is compared with a standard that includes the particular geometrical arrangement of the subarray being tested.

The test antenna is approximately level with the lowest element of the 102-ft array. It is therefore lower than any driven element of the basic system and below the center of any possible subarray. Consequently, the test beam strikes the ground within a few hundred feet of the array face.

Most of the power that is radiated for such tests will strike the ground. However, some of it will be scattered and add to the diffuse time averaged power density associated with the higher order sidelobes.

The power per subarray (rms of pulse) is 582.4/56 = 10.4 kW. The time averaging coefficient for all subarrays is $(56 \times 50 \times 10^{-6})/30 = 9.33 \times 10^{-5}$. The product of these two numbers is the total time-averaged power -- 0.97 watts. This value is compared with $582.4 \times 0.18 \times 0.4 = 41.9$ kW which is the time averaged power distributed in sidelobes from the total radar face, assuming 60% of the power is in the main beam. The ratio of those numbers is about 40,000. Therefore, the power devoted to transmitter diagnostics has no significant effect on the total EMR field.

### A.2.6 Transmitted Pulse Codes

Pulses transmitted by the radar are allocated to specific tasks in accordance with the radar energy requirements of those tasks and the priority allocated to each. In task scheduling, time is divided into radar intervals or "resources" that last 54 milliseconds (ms). In normal operation about half of these resources are used to generate a surveillance fence that has an elevation of 3 to 10 deg and covers an angular sweep of 240 deg in azimuth. Every eighteenth or twentieth resource is used for calibration and performance monitoring. The remaining resources

are available for use in tracking objects detected in the surveillance fence or tasked by the Spacetrack System. The central computer selects transmitted pulse groups from 11 codes according to the position and measured characteristics of objects currently in track, tracked objects entering coverage, and recent detections by the surveillance fence. Each transmitted pulse may be at any of 24 operating frequencies (see Table D-2, p. D-12) within the allocated frequency band of 420 to 450 MHz. The frequency is varied slightly during each pulse to obtain additional information about any target within the beam.

Pulses that produce the surveillance fences are transmitted from both faces simultaneously and at the same relative position. All other pulses are transmitted from one face or the other but never simultaneously.

Under normal circumstances each face of the radar emits power ++
about 18% of the time. That is, the duty cycle averages 18%. The duty cycle used for maintaining the routine surveillance fence averages 11%. Under very exceptional circumstances of heavy tracking assignment the duty cycle of either face can be increased to 25%; under those conditions the duty cycle of the other face is necessarily reduced to 11%. The principal significance of these statements with respect to the EMR field at ground level is that the duty cycle reduces the time-averaged power density. The maximum possible duty cycle of 25% is used in subsequent calculations in the interest of estimating the maximum possible power density. Power densities corresponding to 18% duty cycle should be used in all considerations of long-term cumulative exposure, as in Section 3.1.1.1, p. 3-2.

## A.3 EMR Field Model Description

### A.3.1 Introduction and Assumptions

A large antenna that is many wavelengths in diameter produces a radiation field that is concentrated in a small volume of space and is commonly referred to as a narrow or pencil beam. The PAVE PAWS antenna falls into this class. The major characteristics of such a pencil beam radiation field are determined by the following features of the array:

(1) Shape

(2) Diameter in wavelengths

(3) Power distribution

(4) Overall efficiency.

The mathematical description of the complete field produced by large antennas is very complicated. Therefore, approximate expressions have been developed to facilitate calculation

The resulting electromagnetic field is normally described by dividing it into three regions, where different sets of analytical conditions apply. Those regions are the near field, the transition region, and the far field. The boundaries of the three regions are not sharply defined; rather, EMR field conditions gradually change with increasing distance from the face of the antenna. Different approximations apply to the different regions. The boundaries between the regions are defined by the acceptable error in the approximations that are made.

The far field is defined as a region over which the analytic conditions are constant and the fields vary inversely with distance (i.e., the power density varies inversely as the square of the distance). The distance from the array face beyond which the true far field exists is $2D^2/L$, where D is the active array diameter and L is the radiation wavelength. An outer transition region exists at distances between $0.6\ D^2/L$ and $2D^2/L$. Here the field conditions resemble those in the far-field region, but the sidelobes increase slightly in strength, and pattern nulls are somewhat filled in. For convenience and because it involves no significant errors we henceforth treat this outer transition region as part of the far field. In an inner transition region between $0.25\ D^2/L$ and $0.6\ D^2/L$, the sidelobes degenerate into bumps on the sides of the mainbeam.

The near field exists in the region between the antenna face and $0.25\ D^2/L$; here the sidelobes are not identifiable, and the on-axis field strength varies rapidly in a complex manner.

The variation of field strength in the main beam on-axis with distance from a tapered circular antenna such as PAVE PAWS is shown in Figure A-3 for distances out to $2D^2/L$ (Hansen, 1964). As the distance from the antenna face increases, the field strength varies in a cyclic manner; at the distance $0.2\ D^2/L$ the field strength reaches its maximum value, which is 42 times the value at $2D^2/L$. Figure A-3 shows that beyond about $0.6\ D^2/L$ the power density in the beam decreases as the reciprocal of distance squared. In the range $0.25\ D^2/L$ to $0.6\ D^2/L$ the variation is nearly linear; it appears curved because of the logarithmic abscissa scale.

The main beam of the PAVE PAWS radar never strikes or closely approaches the ground. Therefore, calculations of near ground level conditions require consideration of power densities at angles away from the axis of the main beam. In the far field such calculations are based on known sidelobe distributions. At closer distances the procedure is more complicated. Figure A-4, p. A-12, shows the theoretical far field pattern for the PAVE PAWS

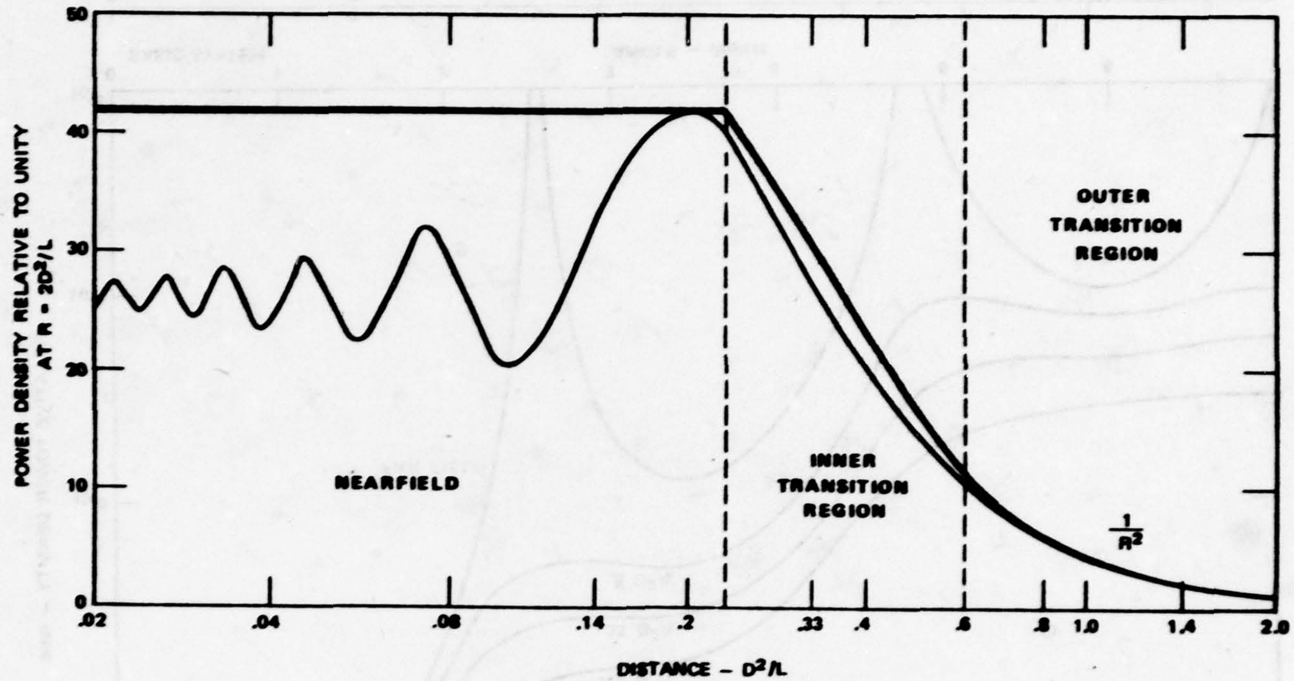


FIGURE A-3. MAIN BEAM ON-AXIS FIELD STRENGTH FOR A CIRCULAR ANTENNA
Heavy Line Represents Values Used in Three Zones

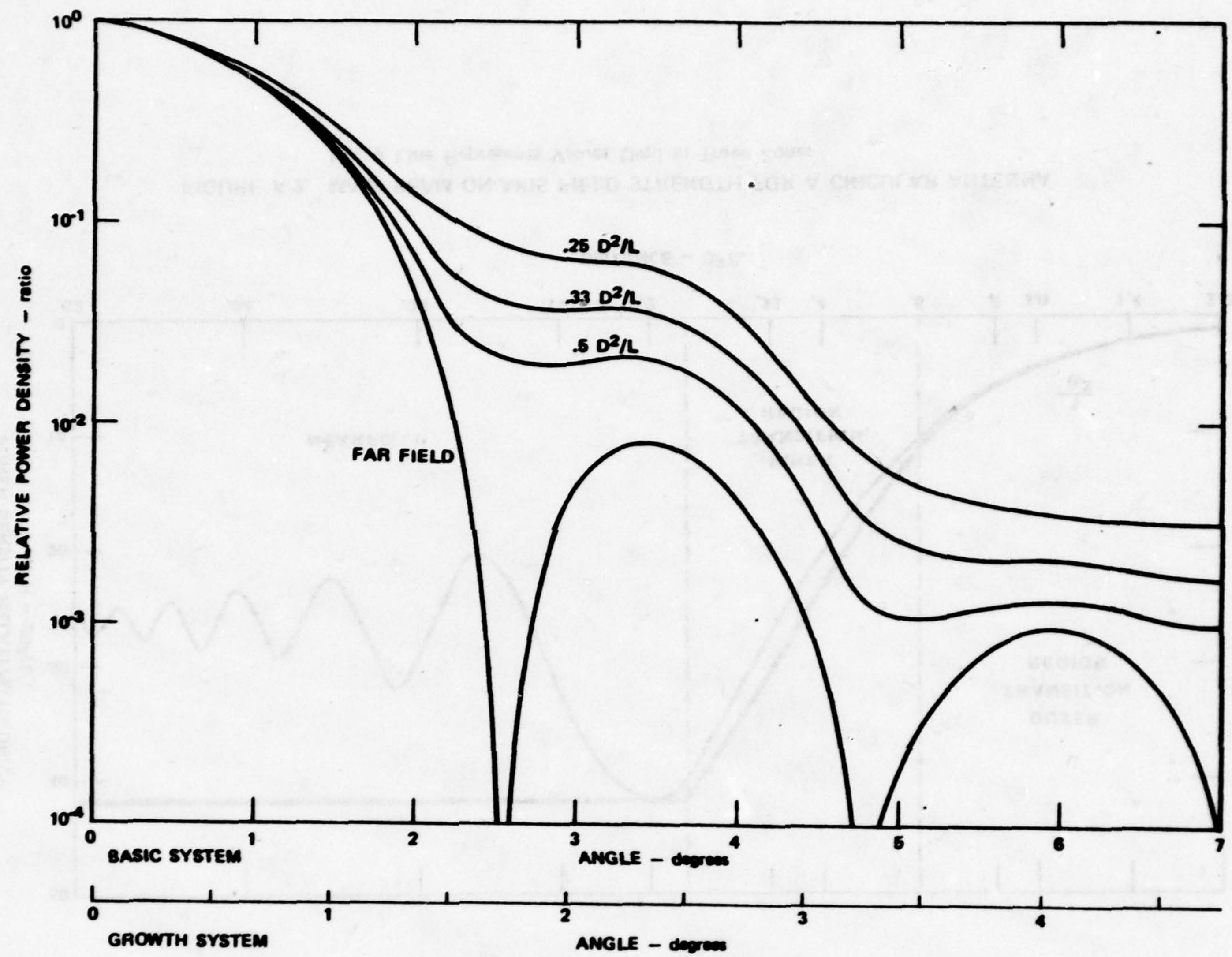


FIGURE A-4. ANTENNA PATTERNS FOR FAR FIELD AND TRANSITION REGION

antenna. Also shown are theoretical patterns for three distances within the transition region (Hu, 1961).

Following the general method used by Hankin, and using some of his text (Hankin 1977) in this and following sections, we calculate the EMR electric field strength and power density at ground level at various locations. To facilitate the calculations of possible radiation exposure we apply the following conditions and assumptions: ++

(1) The phased array antenna can be approximated by a circular aperture, and circular aperture models can be used to calculate EMR fields.

(2) In most cases the greatest possible field strength near ground level will exist when the antenna main beam is pointed in that particular direction and has the minimum elevation angle of 3 deg above the horizontal plane. All calculations of field strength are made for the case of a +3 deg elevation angle.

(3) When directed at the minimum elevation angle of +3 deg (-17 deg relative to the antenna boresight axis), the shapes of the main beam and its sidelobes are assumed to be the same as for the boresight orientation of the main beam. In reality, the gain of the main beam is slightly reduced and the angular dispersion of the sidelobes is slightly increased. The applicable coefficient is cos 17 deg = 0.96, which does not differ significantly from 1.0.

(4) The near-field extent $R_{nf}$ can be approximated by the relationship $R_{nf} = 0.25\ D^2/L$ (Hansen, 1964).

(5) The maximum possible power density in the near field, $W_{nf}$, is assumed to exist throughout the near field along the main beam axis.

(6) The far field is assumed to start at a distance from the antenna of $0.6\ D^2/L$.

(7) In this appendix the calculation of EMR field strengths at any distance from the PAVE PAWS radar up to 10 miles is based on direct line-of-sight propagation because all other modes of propagation are much weaker. Other modes of propagation such as ducting or temperature inversion, diffraction or tropospheric scatter or reflection are weaker because they involve greater path lengths and/or lossy propagation mechanisms (Kerr, 1951; NAS, 1979). + Ground level areas which are shadowed by intervening terrain will be illuminated by the diffraction mode of propagation. The EMR field strengths in such areas will be overestimated because the calculations are based on direct line-of-sight propagation.

### A.3.2 Key Parameters

#### A.3.2.1 Radiation Wavelength L

$L = C/f$      $C$ = speed of light (cm/s)

$L = 3 \times 10^{10}/450 \times 10^{6}$      $f$ = frequency (Hz)

$L = 66.7$ cm or 2.19 ft

#### A.3.2.2 Near-Field Extent, $R_{nf}$

$R_{nf} = 0.25\ D^2/L$

$R_{nf} = 1.83 \times 10^4$ cm or 601 ft (basic system)

$R_{nf} = 3.62 \times 10^4$ cm or 1,190 ft (growth system)

#### A.3.2.3 Start of Far-field, $R_{ff}$

$R_{ff} = 0.6\ D^2/L$

$R_{ff} = 4.39 \times 10^4$ cm or 1,440 ft (basic system)

$R_{ff} = 8.69 \times 10^4$ cm or 2,850 ft (growth system)

### A.3.3 EMR Field Model

#### A.3.3.1 Field Strength On-Axis in the Main Beam at any Distance from the Antenna

At any specific distance R from the antenna, the field strength on-axis in the main beam is given by the following expressions, in which the coefficients are adjusted to conform to our uniform usage of power density in microwatts/cm$^2$, and the symbols have the following meanings:

P = total transmitted power, rms of pulse (Watts) +
G = antenna gain (ratio)
D = active array diameter (cm)
R = distance to antenna (cm)
L = radiation wavelength (cm)

For R less than $0.25\ D^2/L$, the near field pulse power density $W_{nf}$ is: +

$$W_{nf} = \frac{836{,}000\ PGL^2}{D^4} \quad \text{(Hansen, 1964, p. 39)}$$

**This expression for $W_{nf}$ is consistent with a detailed computer calculation of the near field of PAVE PAWS (RADC, 1978). (A later model for a tapered circular aperture by Hansen (1976) would yield slightly smaller values, and Hankin (1977) calculated similar smaller values.)**

**For $R = 0.6\ D^2/L$, at the start of the far field, the pulse power density is:**

$$W_{ff} = \frac{79{,}580\ PGL^2}{0.36\ D^4}.$$

**For R greater than $0.25\ D^2/L$ but less than $0.6\ D^2/L$ (transition region), the on-axis pulse power in the main beam at distance R is obtained by linear interpolation between $W_{ff}$ and $W_{nf}$:**

$$W = W_{ff} + \frac{(W_{nf} - W_{ff})(R_{ff} - R)}{(R_{ff} - R_{nf})}$$

**For R greater than $0.6\ D^2/L$ (far-field)**

$$W = \frac{79{,}580\ PG}{R^2}$$

**For the parameters of the PAVE PAWS basic system and using all distances in feet, these pulse power expressions simplify to**

$W_{nf} = 562{,}500$ **for R less than 601 ft**

$W = 858{,}200 - 492R$ **for R between 601 and 1,440 ft**

$W = (3.09 \times 10^{11})/R^2$ **for R beyond 1,440 ft.**

### A.3.3.2 Field Strength Outside of the Main Beam at any Distance from the Antenna

**Field strengths outside of the main beam are calculated for three distance intervals relative to the antenna. The field strength at any point, a distance R from the antenna center, that is not within the main beam may be calculated by determining the on-axis main beam field strength at that distance and then reducing this figure by the appropriate relative intensity factor for off-axis radiation.**

(1) For R less than 0.25 $D^2/L$:
Field strengths in the near-field region are derived from computer-modeled radiation patterns provided by Rome Air Development Center (RADC, 1978), (see Figure A-8, p. A-25). ++

(2) For R between 0.25 $D^2/L$ and 0.6 $D^2/L$:
Field strength due to transition region radiation can be determined by inspection of the antenna radiation pattern in the transition region (Figure A-4, p. A-12).

(3) For R greater than 0.6 $D^2/L$:
Field strength resulting from far-field radiation can be determined by inspection of the antenna radiation pattern, which is also shown in Figure A-4, p. A-12.

The principal characteristics of the PAVE PAWS EMR are given in Table A-2.

The distribution of power density with azimuth angle at ground level is not uniform around the radar because the azimuth scan coverage is limited to specific sectors. In addition the power density near the ends of the scan limits of each array face is controlled by the radiation pattern of the array element. Figure A-5, p. A-18, shows a polar plot of the array element pattern for both faces and how they overlap. The overlap causes an increase ++
in the power density in the central 60-deg sector. In order to simplify the estimate of maximum power density as a function of azimuth, the power density attributed to higher order sidelobes has been assumed doubled in the overlap region (with 18% duty cycle on both faces as assumed in Section 3.1.1) and constant to +
30 deg beyond the ends of the scan coverage as indicated by the dotted line. For the 25% duty cycle used in this appendix, and with the remaining available 11% applied to the other face, power density has been assumed to increase by 44% in the overlap region in comparison with the remaining region in the scan of the face at 25% duty cycle. The result is that the maximum power density assumed for the overlap region relates only to the total combined duty cycle for both faces (36%) regardless of the proportion to each array face.

### A.3.3.3 Beam Motion Effects

In PAVE PAWS operation, the main beam is pointed in a given direction only for the duration of a single pulse, after which the main beam is pointed in a different direction, with essentially no overlap at the previous location. The mobility of the radar main beam has an averaging effect on the EMR field power density. In other words it can reduce the effect of the main beam and sidelobes as well as "fill in" nulls between lobes of the field pattern. The averaging factor will differ depending on whether the area is illuminated by the main beam, or some combination of sidelobes. The averaging factor becomes less important at close

Table A-2

CALCULATED SYSTEM CHARACTERISTICS[a]

| System Characteristic | Calculated Values: Basic System | | Calculated Values: Growth System | |
|---|---|---|---|---|
| Near-field extent, $R_{nf}$, cm, (ft) | $1.83 \times 10^4$ | (601) | $3.62 \times 10^4$ | (1,190) |
| Near-field on-axis maximum time-averaged power density, $W_{nf}$ (microwatts/cm$^2$) | 140,000 | | 142,500 | |
| Far-field begins 0.6 $D^2/L$, cm (ft) | $4.39 \times 10^4$ | (1,440) | $8.69 \times 10^4$ | (2,850) |
| On-axis main beam power density at 0.6 $D^2/L$, $W_{ff}$ (microwatts/cm$^2$) | 37,200 | | 37,700 | |
| First sidelobe maximum power density (microwatts/cm$^2$) | 372 | | 377 | |
| Second sidelobe maximum power density (microwatts/cm$^2$) | 37 | | 38 | |

[a]These values are based on the maximum allowable duty cycle of 25%.

ranges where the diameter of the radiation column is comparable to the distance through which it is swept.

The majority of ground level exposure is caused by the secondary (beyond first) sidelobes. Unlike the first sidelobe, these are almost random in nature. The system specification, confirmed by measurements, limits the power of these secondary sidelobes to a maximum value of 0.001 relative to the main beam. The effect of beam motion is to reduce this upper limit to an average value for the secondary sidelobes relative to the main beam of 0.00016 (1/6,200; i.e., -38 dB) for the basic system and 0.000080 (1/12,300; i.e., -41 dB) for the growth system.

The average level of the secondary sidelobes can be estimated by using conservation of energy. The gain of the antenna is 6,200

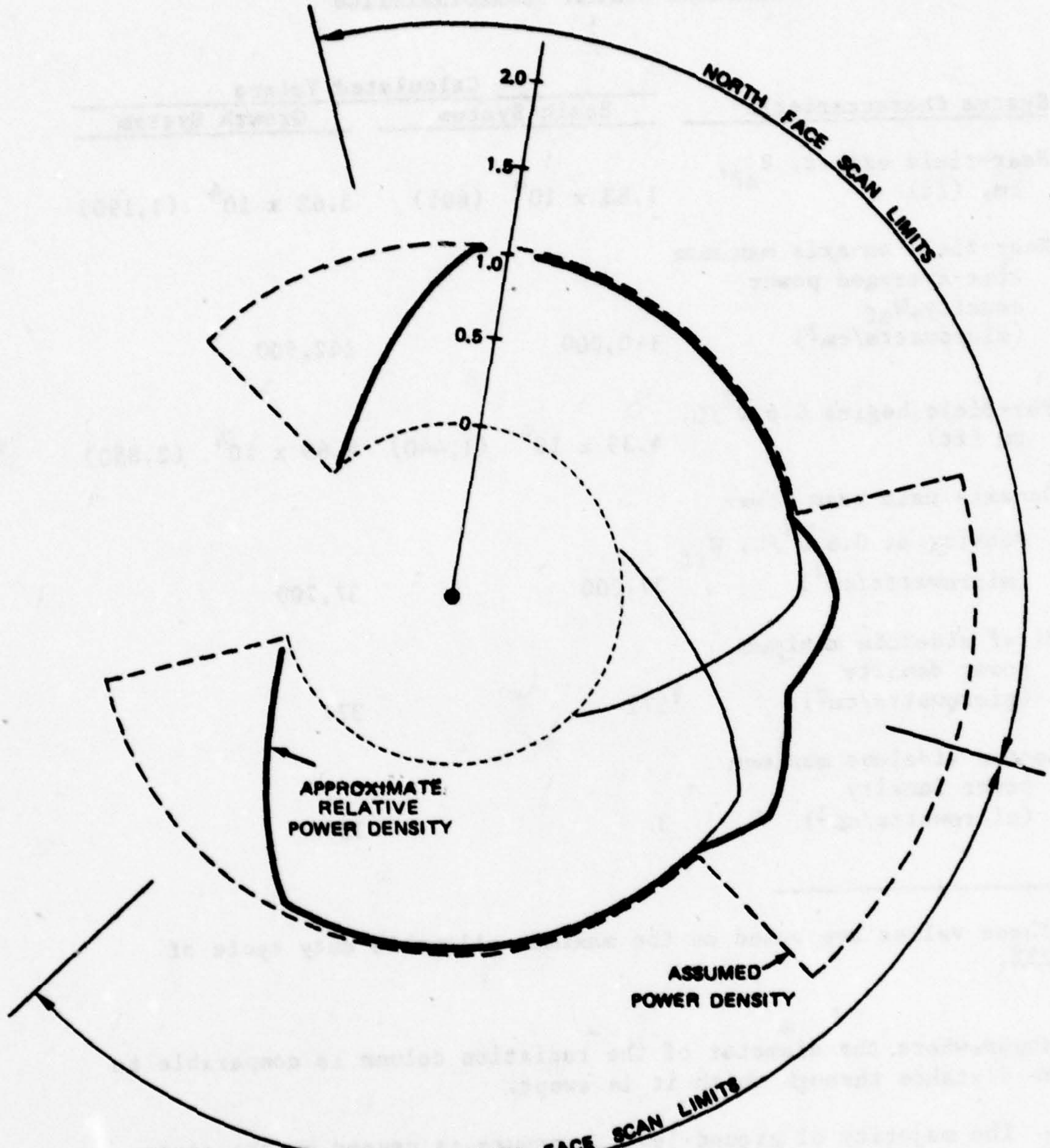


**FIGURE A-5. POLAR PLOT OF RELATIVE POWER DENSITY VARIATION WITH AZIMUTH ANGLE, BASIC SYSTEM, WITH SAME DUTY CYCLE APPLIED TO BOTH FACES ++**

(basic system) relative to an isotropic (nondirectional) reference. Moreover, at least half of the available power is concentrated in the slender main beam. If the remainder of the power were distributed uniformly over the remaining angular space it would be $6,200 \times 2 = 12,400$ times weaker than the main beam, the factor of 2 representing the effect of concentrating half the energy. If the sidelobe power were distributed uniformly in half space, a condition reasonably associated with a flat array, the factor of 2 is cancelled out and the average sidelobe level is $1/6200 = 0.00016$ relative to the main beam. A similar argument produces 0.000080 relative to the main beam for the growth system.

The main beam never intersects the ground and hence does not affect the average power density at ground levels. The first sidelobe does intersect some high ground areas, but only during the surveillance fence mode of operation at an elevation angle of 3 deg and only for the basic system. The surveillance fence uses 60 beam positions mutually separated by 2 deg as shown in Figure A-6. The first null, which represents the boundary of the main beam, occurs 2.6 deg off the main beam axis; i.e., at an elevation +0.4 deg relative to horizontal. The maximum of the first sidelobe occurs at 3.4 deg or -0.4 deg relative to (i.e., below) horizontal. The null of the first sidelobe occurs at 4.8 deg or -1.8 deg relative to horizontal.

As evident in Figure A-6, a particular point P at an elevation of -0.4 deg and halfway between two beam positions receives some first sidelobe energy from four adjacent positions of the main +
beam. The sidelobe power is near maximum for two beam positions, and quite small for the other two. On the basis of this observation the energy contributed to the point is estimated as 2.5 times that contributed by one pulse of the first sidelobe.

Energy is assigned to the surveillance fence during 11% of the ++
time on average. Using this number, the fact that the maximum sidelobe power is 0.01 times that of the main beam, and the 2.5 out of 60 factor resulting from Figure A-6, we conclude that the time averaged power at point P is $(0.11 \times 0.01 \times 2.5/60 + 0.00016/4)$ of the on-axis main beam pulse power density. The last term in the parentheses represents the contribution of random high order sidelobes for a total duty cycle of 25%. The resultant coefficient is 0.000086, of which nearly half is contributed by the secondary sidelobes. Coefficients for other points illuminated by the first sidelobe are calculated similarly.

The beam motion factors used in Tables A-4, 5, 7, and 8, pp. A-27, 29, 34, 35, respectively, account for the effect of the beam motion only. The beam motion factor can be as high as 1.6 for ground level exposure to a null in the far field pattern which is below the average secondary sidelobe level. The beam motion factor would be 1.0 for an elevated location immediately in front of the array. The smallest beam motion factors (0.04) generally apply to ground level exposure to the first sidelobe.

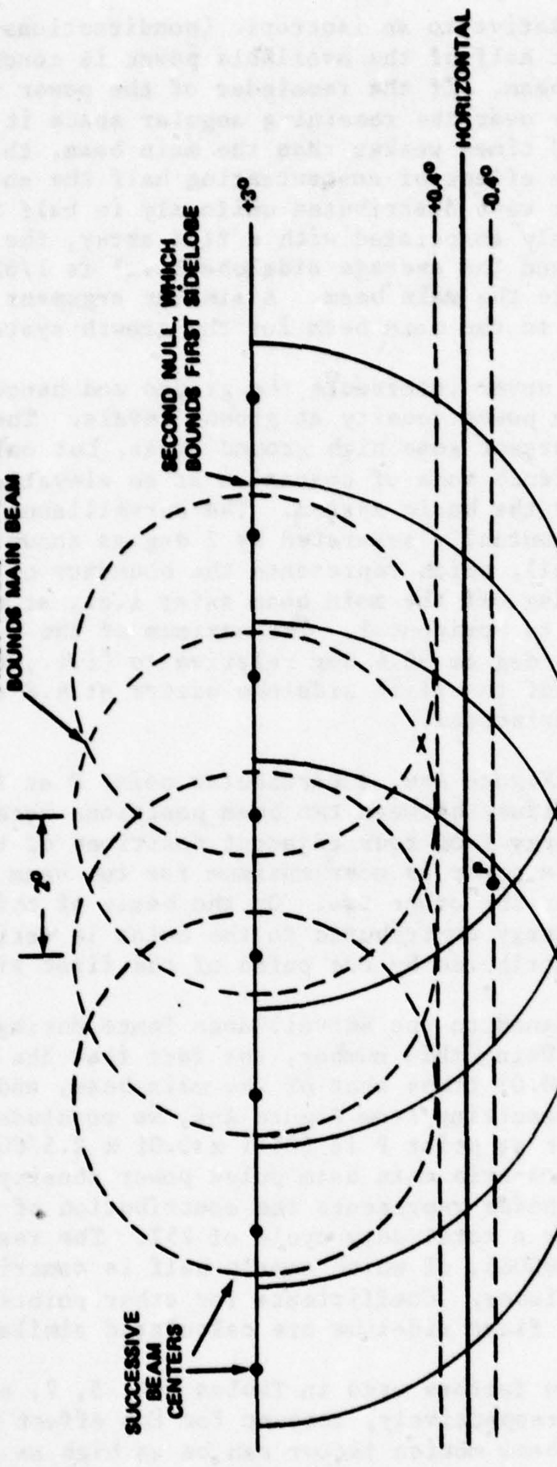


FIGURE A-6. SCANNING EFFECT OF FIRST SIDELOBE BASIC SYSTEM

## A.4 Determination of Ground-Level Field

### A.4.1 Introduction

Values of EMR field strength have been calculated for many selected locations in the vicinity of the PAVE PAWS antenna. The calculated values are intended to represent realistic estimates (i.e., it is expected that the field strength at any given location produced by operation of the PAVE PAWS system may be either larger or smaller (by a factor of 2) than the calculated values). The conditions assumed for the calculation of field strength at any location are: (1) During 11% of the time the radar creates a surveillance fence with a beam elevation of 3 deg; (2) During an additional 14% of the time the radar performs tracking functions using many beams all at elevations above 3 deg; and (3) that the far-field radiation pattern used in the analysis for the main beam elevation angle of +3 deg is the same as Figure A-4, p. A-12; i.e., the pattern in the vertical plane computed for the main beam directed at the antenna boresight. ++

Figure A-7 shows the intersections of the first sidelobe with the ground (in the vertical plane) at Otis for several directions and for both the basic system and the growth system. This figure includes a topographic description of the ground plotted as height above sea level versus distance from the antenna site. The figure provides only a general graphic description of the terrain and the radiation patterns at ground level when the main beam points in the directions specified and the beam axis is at +3 deg. The main beam axis, main beam null, first sidelobe maximum, and first sidelobe null are shown (in the vertical plane) relative to the horizontal at the center of the antenna. The nulls are considered to define the main beam and the first sidelobe; the second sidelobe is assumed to begin immediately after the second null (first sidelobe null). Table A-3, p. A-23, lists regions of ground-level terrain in the far field and the relative sidelobe intensities that illuminate them for the basic system. Figures A-4, p. A-12, and A-7 indicate that the ground is not exposed to main beam or first sidelobe radiation (significantly exceeding secondary sidelobes) from the growth system. The directions chosen in Figure A-7 and Table A-3 represent maximum ground level exposure. The ground falls away more rapidly and exposure is smaller in other directions.

To facilitate general calculations of on-axis main beam field strength at a specific distance r from the antenna, we define r as a distance along the main beam axis. For near surface locations, the points selected for analysis are described by the horizontal distance R between the antenna and the selected location. For the 3 deg elevation angle, $R = r \cos 3 \text{ deg} = 0.999r$. Therefore, horizontal distance R can be used in place of axial distance r with negligible error. +

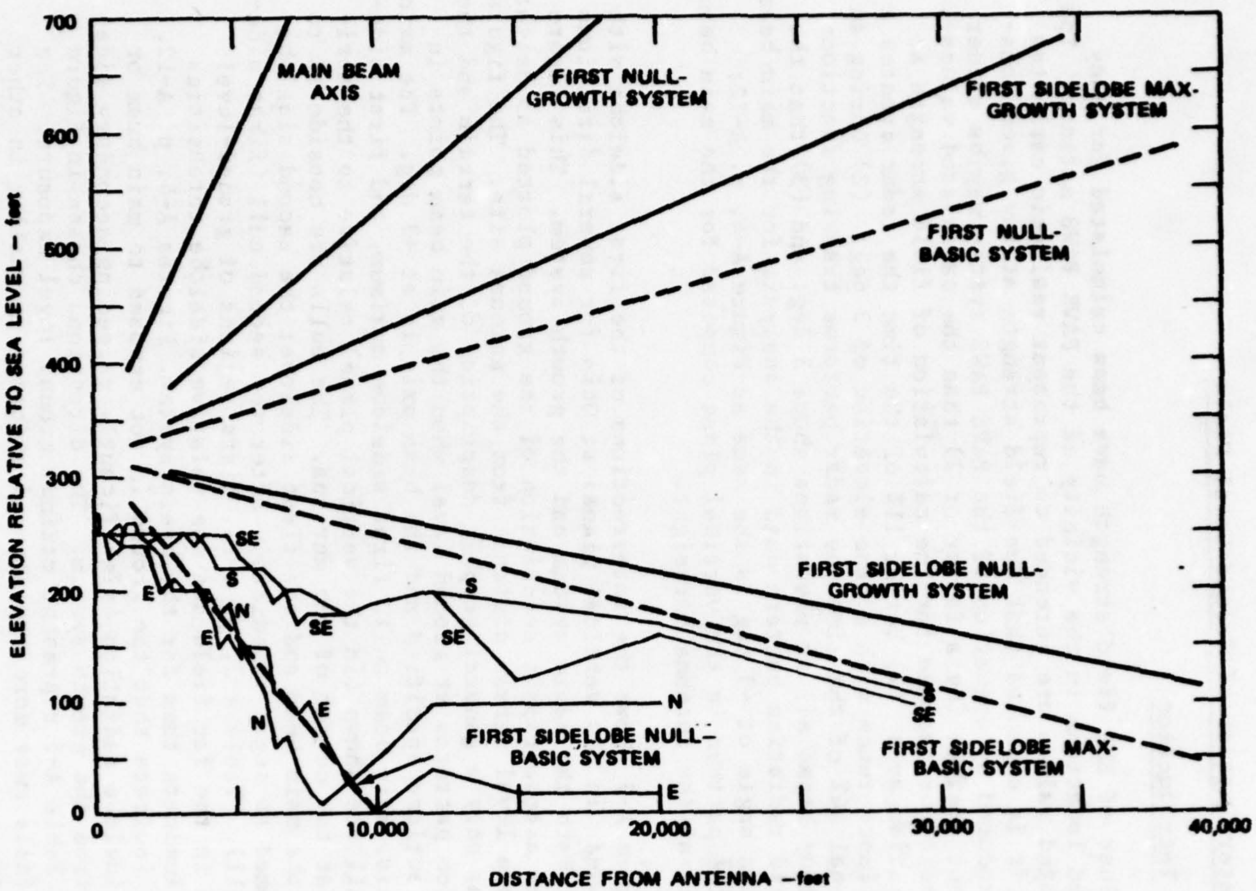


FIGURE A-7. INTERSECTION OF FAR-FIELD RADIATION PATTERNS WITH THE GROUND IN SELECTED DIRECTIONS FROM OTIS AFB PAVE PAWS

Table A-3

**FAR-FIELD SIDELOBE STRENGTH AT GROUND LEVEL -- BASIC SYSTEM -- OTIS AFB**

| Direction | Distance (ft) | Sidelobe Strength Relative to Main Beam |
|---|---|---|
| North | 1,440 to 3,800 | Secondary sidelobe: decreasing from 0.001 at 1,440 ft to 0.0001 at 3,800 ft |
| | 3,800 to 5,100 | First sidelobe: 0.0001 to 4,400 ft, increasing to 0.00032 at 4,800 ft, decreasing to 0.0001 at 5,100 ft |
| | 5,100 to 9,100 | Secondary sidelobe: 0.0001 at 5,100 ft increasing to a value less than 0.001 at 9,100 ft |
| | 9,100 to 20,000 | First sidelobe: 0.0001 at 9,100 ft, increasing to 0.0023 at 12,000 ft, increasing to 0.0032 at 15,000 ft, increasing to 0.0050 at 20,000 ft |
| South | 1,440 to 2,200 | Secondary sidelobe: decreasing from 0.001 at 1,440 ft to 0.0001 at 2,200 ft |
| | 2,200 to 30,000+ | First sidelobe: 0.0001 at 2,200 ft, increasing to 0.0023 at 3,600 ft, decreasing to 0.0014 at 4,400 ft, increasing to 0.0032 at 6,000 ft, increasing to 0.0037 at 9,000 ft, increasing to 0.0063 at 12,000 ft, increasing to 0.0069 at 23,000 ft, decreasing to 0.0063 at 36,000 ft |
| Southeast | 1,440 to 2,200 | Secondary sidelobe: decreasing from 0.001 at 1,440 ft to 0.0001 at 2,200 ft |
| | 2,200 to 30,000 | First sidelobe: 0.0001 at 2,200 ft, increasing to 0.0046 at 4,800 ft, decreasing to 0.0026 at 7,600 ft, increasing to 0.0063 at 12,000 ft, decreasing to 0.0048 at 15,000 ft, increasing to 0.0068 at 20,000 ft, increasing to 0.0069 at 25,600 ft, decreasing to 0.0068 at 30,000 ft |
| East | 1,440 to 5,500 | Secondary sidelobe: decreasing from 0.001 at 1,440 ft to 0.0001 at 2,200 ft |
| | 5,500 to 6,300 | First sidelobe: 0.0001 at 5,500 ft, increasing to 0.001 at 6,000 ft, decreasing to 0.0001 at 6,300 ft |
| | 6,300 to 7,300 | Secondary sidelobe: 0.0001 from 6,300 ft to 7,300 ft |
| | 7,300 to 8,500 | First sidelobe: 0.0001 from 7,300 ft to 8,500 ft |
| | 8,500 to 10,000 | Secondary sidelobe: 0.0001 from 8,500 ft to 10,000 ft |
| | 10,000 to 20,000 | First sidelobe: 0.0001 at 10,000 ft, increasing to 0.0044 at 23,000 ft |

The beam diameter in the near field, considered to be the diameter of the antenna cross-section projected in the direction of the beam axis, is determined by the antenna diameter and the angle between the antenna axis and the beam axis. This angle is 17 deg for the case of the 3 deg elevation angle and the PAVE PAWS face inclination angle of 20 deg. The projected beam diameter, D cos 17 deg = 0.956D, can be approximated by D in calculating off main beam axis distances relative to antenna diameter with negligible effect on the calculated upper limits for off main beam axis field strength in the near-field regions.

### A.4.2 Near-Field ++

The power density that exists near ground level in the near field for the basic and growth systems can be estimated by using antenna elevation patterns generated by computer modeling (RADC, 1978) and reproduced with minor changes in Figure A-8a. The center of the array face is 53 ft above ground level. Thus points at ground level that are 145, 290 and 580 ft respectively in front of the array face center are below the horizontal at (depression) angles of $20^{o}$, $10.4^{o}$, and $5.2^{o}$, respectively.

Those critical angles appear on the three curves. The greatest power density, relative to the maximum on-axis power density in the near field, for any larger angle is then expressed by the ratios: 0.025, 0.0126, and 0.00125 respectively. Those values determine the maximum average power density that strikes the ground directly below the beam at the specified distance. These values, modified by the beam motion factor result in time averaged ground level power densities. Values corresponding to the three given distances were plotted to produce the values presented in Table A-4, p. A-27. Values for the growth system were computed in a similar way using data like that shown in Figure A-8b, p. A-26.

### A.4.3 Transition Region

The field strength in the transition region near ground level is determined for selected locations near the PAVE PAWS site. The on-axis main beam average power density is determined by making a linear interpolation between values computed at distances of 0.25 $D^2/L$ and 0.6 $D^2/L$. As shown in Figure A-3, p. A-11, the on-axis main beam power density decreases almost linearly with increasing distance within the transition region.

The off main beam axis angle is computed by using the distance from the site location to the antenna and the height of the antenna beam center above the site location. The distance to the site location is converted into fractions of $D^2/L$. Using the family of curves shown in Figure A-4, p. A-12, which are parametric in $D^2/L$, a relative strength for the site location is

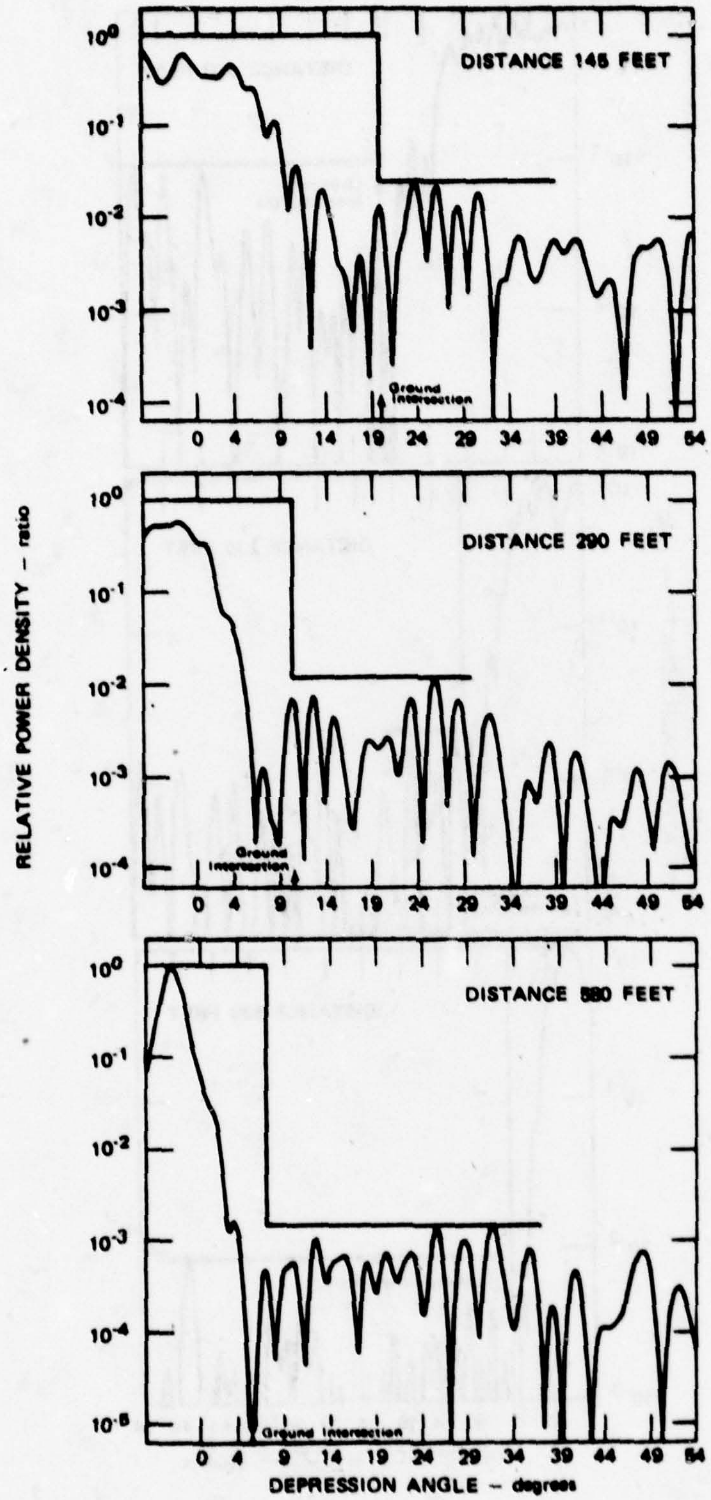


FIGURE A-8a. ANTENNA NEAR-FIELD ELEVATION PATTERNS, BASIC SYSTEM ++

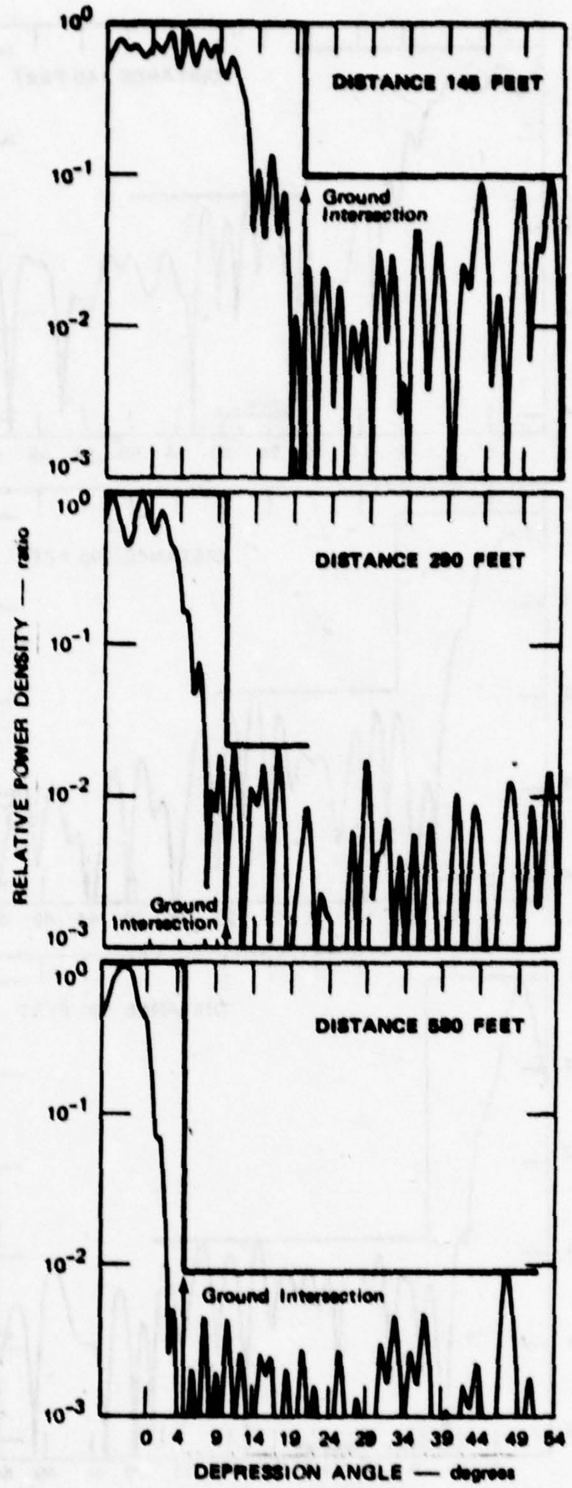


FIGURE A-8b. ANTENNA NEAR-FIELD ELEVATION PATTERNS, GROWTH SYSTEM

Table A-4

NEAR-FIELD GROUND LEVEL POWER DENSITY
PAVE PAWS System - Otis AFB

| System | R (ft) | On Main Beam[d] Axis Average Power Density[c] (microwatts/cm$^2$) | Off Main Beam Axis Angle (Deg) | Relative Intensity (Ratio) | Off Main Beam Axis (Ground Level) Average Power Density[a,c] (microwatts/cm$^2$) | Beam Motion Factor[b] (Ratio) | Ground Level Moving Beam Average Power Density[c] (microwatts/cm$^2$) |
|---|---|---|---|---|---|---|---|
| Basic | 100 | 140,000 | 30.9 | .0317 | 4,440 | .9 | 4,000 |
| (0.25 $D^2/L$ = 601') | 200 | 140,000 | 17.8 | .0158 | 2,210 | .3 | 663 |
| | 400 | 140,000 | 10.5 | .0063 | 880 | .2 | 176 |
| | 600 | 140,000 | 8.0 | .0013 | 170 | .15 | 25 |
| Growth | 100 | 142,500 | 30.9 | .101 | 14,300 | .9 | 12,900 |
| (0.25 $D^2/L$ = 1190') | 200 | 142,500 | 17.8 | .0400 | 5,700 | .3 | 1,710 |
| | 400 | 142,500 | 10.5 | .0158 | 2,250 | .2 | 450 |
| | 600 | 142,500 | 8.0 | .0035 | 500 | .15 | 75 |
| | 1,000 | 142,500 | 6.0 | .0020 | 285 | .1 | 29 |
| | 1,190 | 142,500 | 5.6 | .0013 | 185 | .1 | 19 |

a The off main beam axis average power densities for both the basic system and the growth system have been calculated using computer generated near-field antenna patterns (RADC, 1978), an improvement over methods used in earlier documents (Hankin, 1977).

b The beam motion factor decreases rapidly with distance because of the shape of the beam in the near field.

c These values are based on a maximum possible 25% duty cycle.

d Not ground level.

found. The field strength near ground level is equal to the on-axis main beam value reduced by the relative strength value. Table A-5 lists the locations and the computed field strengths.

### A.4.4 Far Field

Far field strength near ground level is determined for 22 selected locations in the general area around the PAVE PAWS site at Otis AFB. These locations are listed in Table A-6, p. A-30, and described by horizontal distances from the antenna site, ground elevation, and the general direction of the selected location relative to the antenna. Each location is given an identification number. A visual portrayal of the selected locations with regard to the antenna site is provided in Figures A-9, p. A-31, and A-10, p. A-32.

The positions of these selected locations in the far-field radiation pattern of the basic and growth systems, with the main beam axis elevation angle at 3 deg, are shown in Figure A-11, p. A-33. Eight of the selected locations receive EMR from the basic system first sidelobe, relative intensities in the range 0.001 to 0.01, when the beam is oriented in their general direction. Growth system first sidelobe EMR may occur for only two locations, and the relative intensities in both cases are less than 0.001. Main beam EMR to any location does not occur for a 3 deg minimum elevation angle.

Calculations of near ground-level field strength produce the results shown in Tables A-7 and A-8, pp. A-34 and A-35, for the basic and growth systems, respectively. Main beam on-axis field strength at the distance from the antenna of each selected location and the maximum relative intensity to which each location is exposed are given to permit calculation of the maximum electric field intensity. The time-averaged power density for a moving beam is computed by multiplying the stationary beam power density values by the beam motion factor.

The electric field intensities shown are derived from the corresponding power densities by using the relationship

$$E_p = (3.77\ W_p)^{1/2} \quad ,$$

where $E_p$ is the electric field intensity (V/m) and $W_p$ is the pulse power density (microwatts/cm$^2$).

‡

Table A-5

TRANSITION REGION GROUND LEVEL POWER DENSITY
PAVE PAWS SYSTEM, OTIS AFB

| System | R (ft) | R ($D^2/L$) | On Main Beam[d] Axis Average Power Density[c] (microwatts/cm²) | Off Main Beam Axis Angle (Deg) | Relative Intensity (Ratio) | Off Main Beam Axis (Ground Level) Average Power Density[c] (microwatts/cm²) | Beam Motion Factor[b] (Ratio) | Ground Level Moving Beam Average Power Density[c] (microwatts/cm²) |
|---|---|---|---|---|---|---|---|---|
| Basic | 1,000 | 0.42 | 91,000 | 7.0 | 0.0013 | 115 | 0.13 | 15.0 |
| (.6 $D^2/L$ = 1440') | 1,400 | 0.58 | 38,000 | 5.9 | 0.0013 | 48 | 0.13 | 6.2 |
| Growth | 1,400 | 0.29 | 129,000 | 5.9 | 0.0032 | 408 | 0.040 | 16.1 |
| (.6 $D^2/L$ = 2850') | 2,000 | 0.42 | 91,000 | 5.0 | 0.0013 | 115 | 0.065 | 7.5 |
| | 2,190[a] | 0.46 | 80,000 | 5.1 | 0.0013 | 101 | 0.065 | 6.6 |
| | 2,690[b] | 0.56 | 48,000 | 5.5 | 0.0013 | 60 | 0.065 | 4.0 |
| | 2,800 | 0.59 | 38,000 | 4.4 | 0.001 | 38 | 0.080 | 3.0 |

a Gibbs Road at the 227 deg. radial, includes source/site elevation difference of 27 ft.

b Proposed Route 25 at point closest to antenna, includes source/site elevation difference of 67 ft.

c These values are based on a maximum possible 25% duty cycle.

d Not ground level.

Table A-6

LOCATIONS FOR FAR-FIELD ESTIMATES

| Location | Location Number | Distance (ft) | Elevation (ft) | General Direction |
|---|---|---|---|---|
| Antenna site | - | - | 270 | - |
| Gibbs Road - along 227 deg radial | 1 | 2,190 | 240 | SW |
| Proposed Route 25 - closest to antenna | 2 | 2,690 | 200 | N |
| Proposed Route 25 - along 347 deg radial | 3 | 2,890 | 210 | N |
| U.S. 6 - closest to antenna | 4 | 3,450 | 200 | NE |
| U.S. 6 - north | 5 | 4,180 | 200 | N |
| U.S. 6 - east | 6 | 5,640 | 150 | E |
| Sandwich | | | | |
| Nearest housing | 7 | 5,200 | 100 | E |
| Camping area | 8 | 5,380 | 100 | NE |
| Housing | 9 | 6,180 | 150 | NE |
| Housing | 10 | 6,380 | 100 | NE |
| Camping area | 11 | 6,575 | 70 | E |
| Housing | 12 | 8,370 | 50 | E |
| Sagamore | | | | |
| Nearest housing | 13 | 5,780 | 130 | N |
| Sagamore Bridge | 14 | 8,470 | 275 | N |
| Sagamore School | 15 | 9,460 | 30 | N |
| Canal View Road - 227 deg radial | 16 | 15,480 | 100 | SW |
| Pine Hill tower | 17 | 17,733 | 230 | SW |
| Telegraph Hill tower | 18 | 15,940 | 292 | SE |
| Otis structures | 19 | 25,500 | 150 | S |
| Otis structures | 20 | 29,500 | 140 | SW |
| North Pocasset | 21 | 26,100 | 50 | SW |
| Otis Schools | 22 | 36,500 | 90 | SW |

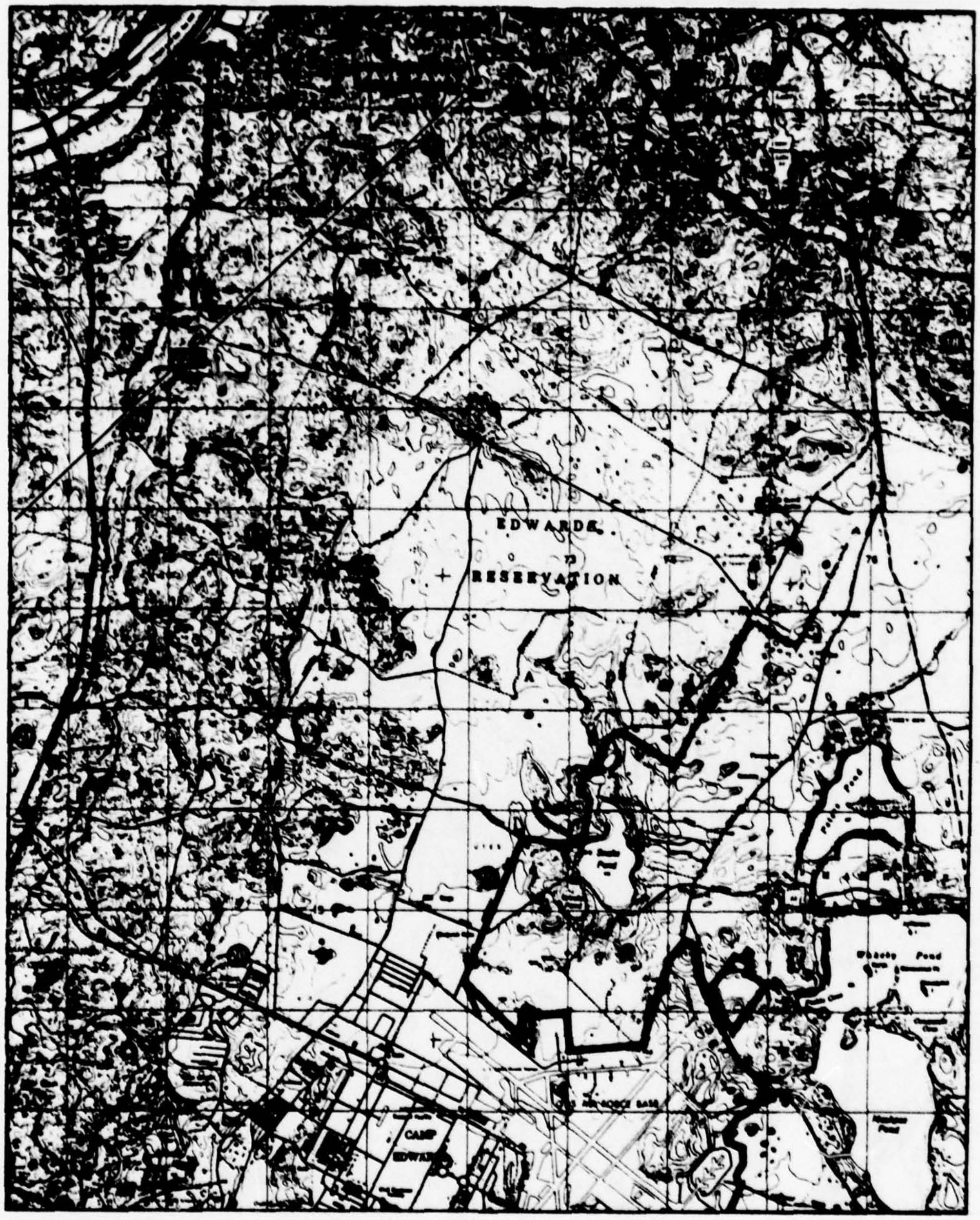


FIGURE A-9. OTIS AFB – SITES SELECTED FOR ANAYSIS AND TOPOGRAPHY

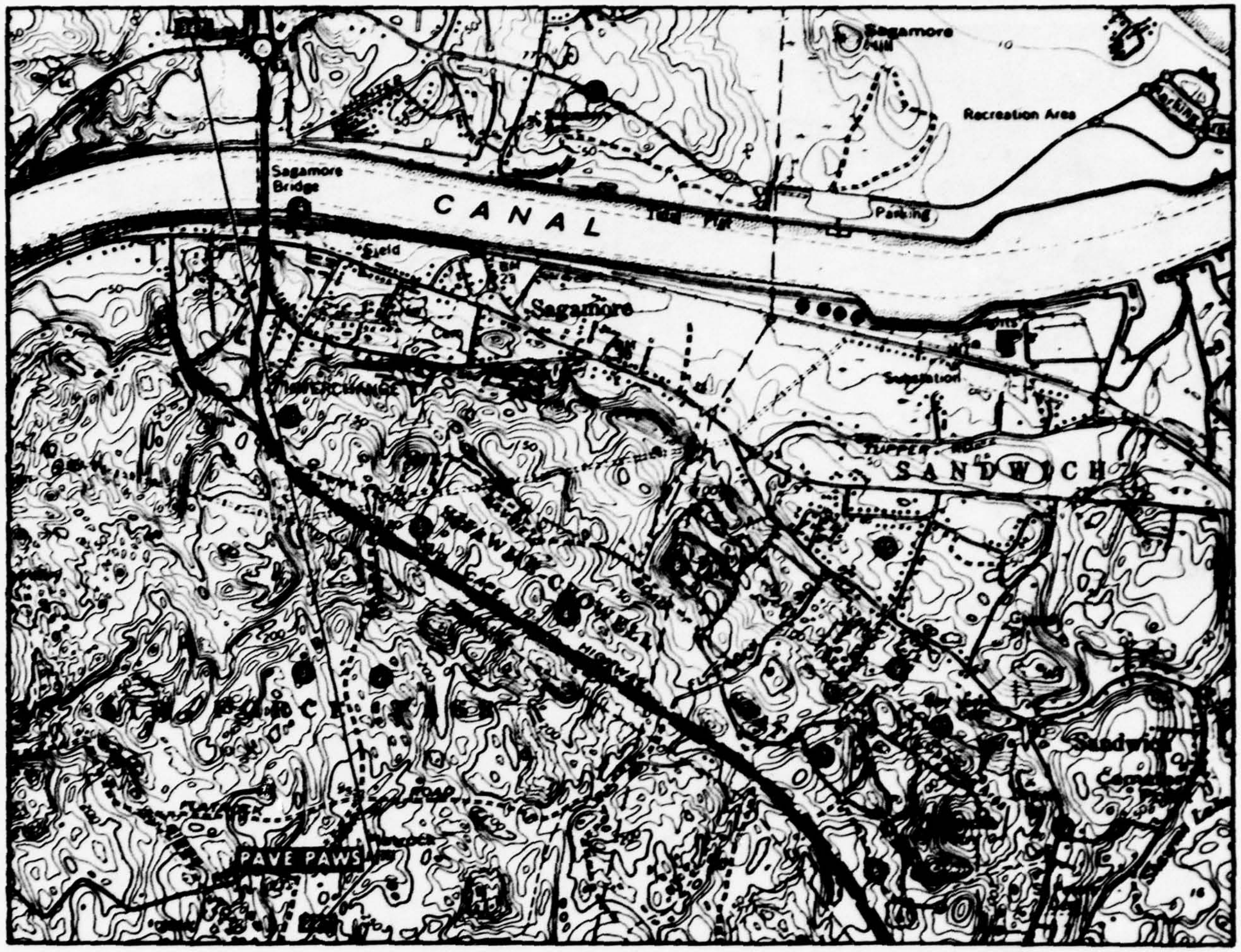


FIGURE A-10. OTIS AFB – OTHER SITES NEAR PAVE PAWS

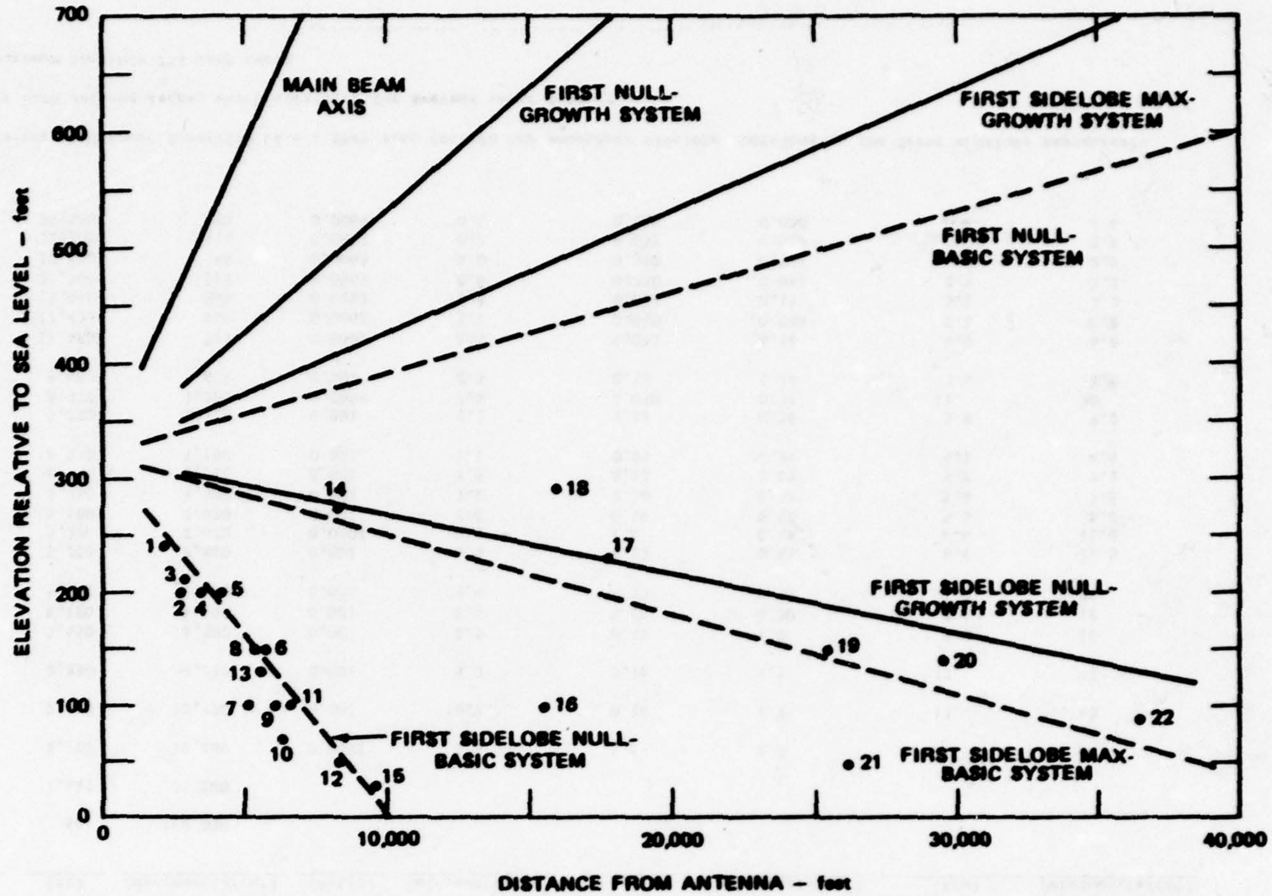


FIGURE A-11. SELECTED LOCATIONS IN THE FAR-FIELD RADIATION PATTERNS: BASIC AND GROWTH SYSTEMS – OTIS AFB

Table A-7
FAR-FIELD GROUND LEVEL EMR - BASIC SYSTEM
PAVE PAWS SYSTEM, OTIS AFB

++

| Location | Location Number | Distance (ft) | On Main Beam[d] Axis Average Power Density[c] (microwatts/cm²) | Relative Intensity (Ratio) | Off Main Beam Axis (Ground Level) Average Power Density[c] (microwatts/cm²) | Beam Motion Factor (Ratio) | Ground Level Moving Beam Average Power Density[a,c] (microwatts/cm²) | Ground Level Maximum Electric Field Intensity (V/m) | Ground Level Maximum Pulse Power Density (microwatts/cm²) |
|---|---|---|---|---|---|---|---|---|---|
| Near-field extent ($0.25\ D^2/L$) | | 601 | 140,000 | | | | | | |
| Beginning of far-field ($0.6\ D^2/L$) | | 1,442 | 37,200 | | | | | | |
| Gibb's Road - along 227 deg. radial | 1 | 2,190 | 16,100 | 0.0001 | 1.6 | 1.6 | 2.5 | 16. | 64 |
| Proposed Route 25 - closest to antenna | 2 | 2,690 | 10,700 | 0.001 | 10.7 | 0.16 | 1.7 | 13. | 43 |
| Proposed Route 25 - along 347 deg. radial | 3 | 2,890 | 9,260 | 0.001 | 9.3 | 0.16 | 1.5 | 12. | 37 |
| U.S. 6 - closest to antenna | 4 | 3,450 | 6,500 | 0.001 | 6.5 | 0.16 | 1.0 | 9.9 | 26 |
| U.S. 6 - north | 5 | 4,180 | 4,430 | 0.001 | 4.4 | 0.16 | 0.70 | 8.1 | 18 |
| U.S. 6 - east | 6[b] | 5,640 | 2,430 | 0.001 | 2.4 | 0.23 | 0.55 | 6.0 | 96 |
| Sandwich | | | | | | | | | |
| Nearest housing | 7[b] | 5,200 | 2,860 | 0.001 | 2.9 | 0.23 | 0.66 | 6.6 | 11.6 |
| Camping area | 8 | 5,380 | 2,670 | 0.0001 | 0.3 | 1.6 | 0.48 | 6.4 | 12.0 |
| Housing | 9 | 6,180 | 2,020 | 0.001 | 2.0 | 0.16 | 0.32 | 5.5 | 8.0 |
| Housing | 10 | 6,380 | 1,900 | 0.001 | 1.9 | 0.16 | 0.30 | 5.4 | 7.6 |
| Camping area | 11[b] | 6,575 | 1,790 | 0.001 | 1.8 | 0.23 | 0.42 | 5.2 | 7.2 |
| Housing | 12[b] | 8,370 | 1,100 | 0.001 | 1.1 | 0.23 | 0.24 | 4.1 | 4.4 |
| Sagamore | | | | | | | | | |
| Nearest housing | 13 | 5,780 | 2,320 | 0.001 | 2.3 | 0.16 | 0.36 | 5.9 | 9.2 |
| Sagamore Bridge | 14 | 8,370 | 1,100 | 0.0069 | 7.6 | 0.050 | 0.37 | 11. | 30 |
| Sagamore School | 15 | 9,460 | 864 | 0.001 | 0.9 | 0.16 | 0.14 | 3.6 | 3.6 |
| Canal View Road - 227 deg. radial | 16 | 15,480 | 323 | 0.0047 | 1.5 | 0.073 | 0.11 | 4.8 | 6.0 |
| Pine Hill tower | 17 | 17,733 | 246 | 0.0069 | 1.7 | 0.050 | 0.084 | 5.1 | 6.8 |
| Telegraph Hill tower | 18[b] | 15,940 | 304 | 0.0062 | 1.8 | 0.072 | 0.15 | 5.2 | 7.2 |
| Otis structures | 19 | 25,500 | 119 | 0.0069 | 0.8 | 0.050 | 0.041 | 3.5 | 3.2 |
| Otis structures | 20 | 29,500 | 89 | 0.0069 | 0.6 | 0.050 | 0.031 | 3.0 | 2.4 |
| North Pocasset | 21 | 26,100 | 114 | 0.0062 | 0.7 | 0.055 | 0.039 | 3.2 | 2.8 |
| Otis schools | 22 | 36,500 | 58 | 0.0069 | 0.4 | 0.050 | 0.020 | 2.4 | 1.6 |

[a] Exposures are the maximum time-averaged power densities (i.e., they also include the secondary sidelobe contribution for first sidelobe exposures).

[b] These locations are exposed by both antenna faces, which increases the average power density.

[c] These values are based on a maximum possible 25% duty cycle.

[d] Not ground level.

Table A-8
FAR-FIELD GROUND LEVEL EMR - GROWTH SYSTEM
PAVE PAWS SYSTEM, OTIS AFB

| Location | Location Number | Distance (ft) | On Main Beam[e] Axis Average Power Density[d] (microwatts/cm$^2$) | Relative Intensity (Ratio) | Off Main Beam Axis (Ground Level) Average Power Density[d] (microwatts/cm$^2$) | Beam Motion Factor (Ratio) | Ground Level Moving Beam Average Power Density[a,d] (microwatts/cm$^2$) | Ground Level Maximum Electric Field Intensity (V/m) | Ground Level Maximum Pulse Power Density (microwatts/cm$^2$) |
|---|---|---|---|---|---|---|---|---|---|
| Near-field extent (0.25 $D^2/L$) | | 1,190 | 142,500 | | | | | | |
| Beginning of far-field (0.6 $D^2/L$) | | 2,850 | 37,700 | | | | | | |
| Gibb's Road - along 227 deg. radial | 1 | 2,190[b] | 79,500 | 0.0013 | 103. | 0.065 | 6.7 | 39. | 412 |
| Proposed Route 25 - closest to antenna | 2 | 2,690[b] | 48,000 | 0.0013 | 62. | 0.065 | 4.0 | 30. | 248 |
| Proposed Route 25 - along 347 deg. radial | 3 | 2,890 | 36,800 | 0.001 | 37. | 0.080 | 2.9 | 24. | 148 |
| U.S. 6 - closest to antenna | 4 | 3,450 | 25,800 | 0.001 | 26. | 0.080 | 2.0 | 20. | 104 |
| U.S. 6 - north | 5 | 4,180 | 17,600 | 0.001 | 18. | 0.080 | 1.40 | 16. | 72 |
| U.S. 6 - east | 6[c] | 5,640 | 9,650 | 0.001 | 10. | 0.12 | 1.10 | 12. | 40 |
| Sandwich | | | | | | | | | |
| Nearest housing | 7[c] | 5,200 | 11,400 | 0.001 | 11. | 0.12 | 1.30 | 13. | 44 |
| Camping area | 8 | 5,380 | 10,600 | 0.001 | 10. | 0.080 | 0.84 | 13. | 40 |
| Housing | 9 | 6,180 | 8,040 | 0.001 | 8.0 | 0.080 | 0.64 | 11. | 32 |
| Housing | 10 | 6,380 | 7,540 | 0.001 | 7.5 | 0.080 | 0.60 | 11. | 30 |
| Camping area | 11[c] | 6,575 | 7,100 | 0.001 | 7.1 | 0.12 | 0.81 | 10. | 28 |
| Housing | 12[c] | 8,370 | 4,380 | 0.001 | 4.4 | 0.12 | 0.50 | 8.1 | 18 |
| Sagamore | | | | | | | | | |
| Nearest housing | 13 | 5,780 | 9,190 | 0.001 | 9.2 | 0.080 | 0.73 | 12. | 37 |
| Sagamore Bridge | 14 | 8,370 | 4,380 | 0.0001 | 0.44 | 0.80 | 0.35 | 8.1 | 18 |
| Sagamore School | 15 | 9,460 | 3,430 | 0.001 | 3.4 | 0.080 | 0.27 | 7.2 | 13.6 |
| Canal View Road - 227 deg. radial | 16 | 15,480 | 1,280 | 0.001 | 1.3 | 0.080 | 0.10 | 4.4 | 5.2 |
| Pine Hill tower | 17 | 17,733 | 976 | 0.0001 | 0.098 | 0.80 | 0.078 | 3.8 | 3.9 |
| Telegraph Hill tower | 18[c] | 15,940 | 1,210 | 0.001 | 1.2 | 0.12 | 0.14 | 4.3 | 4.8 |
| Otis structures | 19 | 25,500 | 472 | 0.001 | 0.5 | 0.080 | 0.038 | 2.7 | 2.0 |
| Otis structures | 20 | 29,500 | 353 | 0.001 | 0.4 | 0.080 | 0.028 | 2.3 | 1.6 |
| North Pocasset | 21 | 26,100 | 451 | 0.001 | 0.4 | 0.080 | 0.036 | 2.6 | 1.6 |
| Otis schools | 22 | 36,500 | 230 | 0.001 | 0.2 | 0.080 | 0.018 | 1.9 | 0.8 |

[a] Exposures are the maximum time-averaged power densities

[b] These distances are not in the far field of the growth system, but in the transition region. They are included in this table to make the description of exposures at the locations selected for analysis complete.

[c] These locations are exposed by both antenna faces, which increases the average power density.

[d] These values are based on a maximum possible 25% duty cycle.

[e] Not ground level.

## A.5 Summary

Maximum time averaged power densities at ground level at locations within the exclusion fence do not exceed 4,000 microwatts/$cm^2$ (12,900 microwatts/$cm^2$ for the growth system); they decrease at the exclusion fence (1,000 ft) to 15 microwatts/$cm^2$ for the basic system (increased in the overlap sector), and to 29 microwatts/$cm^2$ for the growth system . Ground-level time-averaged power densities continue to decrease as distance (beyond the fence) increases, in a manner difficult to describe quantitatively, until the far-field region begins. At that point, 1,440 and 2,850 feet from the antenna for the basic and growth systems, respectively, time-averaged power density exposures are caused mainly by secondary sidelobes. The time-averaged power densities at the beginning of the far field are 5.86 and 2.92 microwatts/$cm^2$ for the basic and growth systems, respectively (increased in the overlap sector).

The time-averaged power densities at any far-field location, in any direction from the antenna site, cannot exceed those calculated for continuous exposure to secondary sidelobes at a relative intensity of 0.001, because exposure to main beam radiation does not occur.

Maximum electric field intensities at any location are derived from the maximum pulse power density possible at that location, i.e., power density caused either by first or secondary sidelobe momentary exposure during beam scanning operation.

A summary of the calculated maximum expected time-averaged power densities and electric field intensities is shown in Table A-9. Several of the locations nearest the PAVE PAWS antenna, on the Base itself, on nearby roads, and in adjacent communities, are included.

Table A-9

**SUMMARY OF GROUND LEVEL FIELD STRENGTHS**
**PAVE PAWS SYSTEM, OTIS AFB**

| Location | No. | Distance (ft) | Average Power Density[a] (microwatts/cm$^2$) | | Maximum Electric Field Intensity (V/m) | | Maximum Pulse Power Density (microwatts/cm$^2$) | |
|---|---|---|---|---|---|---|---|---|
| | | | Basic | Growth | Basic | Growth | Basic | Growth |
| Exclusion Fence | | 1,000 | 15[b] | 29 | 42 | 66 | 470 | 1,150 |
| | | 1,440 | 5.9[b] | 16[b] | 27 | 78 | 190 | 1,600 |
| Gibbs Road | 1 | 2,190 | 2.5 | 6.7 | 16 | 39 | 64 | 412 |
| Proposed Route 25 | 2 | 2,690 | 1.7 | 4.0 | 13 | 30 | 43 | 248 |
| U.S. 6 | 4 | 3,450 | 1.0 | 2.0 | 9.9 | 20 | 26 | 104 |
| Sandwich, nearest housing | 7 | 5,200 | 0.66 | 1.30 | 6.6 | 13 | 11.6 | 44 |
| Sagamore, nearest housing | 13 | 5,780 | 0.36 | 0.73 | 5.9 | 12 | 9.2 | 37 |
| Sagamore School | 15 | 9,460 | 0.14 | 0.27 | 3.6 | 7.2 | 3.6 | 13.6 |
| Otis Bldgs. | 19 | 25,500 | 0.041 | 0.038 | 3.5 | 2.7 | 3.2 | 2.0 |
| North Pocasset | 21 | 26,100 | 0.039 | 0.036 | 3.2 | 2.6 | 2.8 | 1.6 |
| Otis Schools | 22 | 36,500 | 0.020 | 0.018 | 2.4 | 1.9 | 1.6 | 0.8 |

[a] These values are based on a maximum possible 25% duty cycle.

[b] Increased in overlap region, see Figure A-5, p. A-18.

## A.6 References


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## Appendix B

## ELECTROMAGNETIC RADIATION (EMR) FIELD MEASUREMENTS AND COMPARISON WITH CALCULATIONS

### B.1 Introduction

This appendix describes the measurements that were made to evaluate both the ambient and the PAVE PAWS EMR fields and compares them to the calculated PAVE PAWS EMR field. On 15 June 1978, an Air Force/ECAC team carried out measurements of the ambient fields at and near Otis AFB. Subsequently, during July 1978, a team from the National Bureau of Standards made additional measurements of the ambient fields. These measurements were conducted to determine the ambient EMR environment produced by sources such as radio and television stations, other radars, and local communication links. On 26 August, 20 October, and 21 October 1978, an Air Force survey team measured the EMR field radiated from the PAVE PAWS antenna system at many locations in the near and far field. On 3-5 October, an Air Force/ECAC team made other measurements of PAVE PAWS EMR.

### B.2 Ambient Field Measurements

The measurements (Boyne, 1978) made during June and July indicate that the ambient power densities produced by all existing sources (mainly by radio and television stations) are at least 100 times weaker than the power density that will be produced by the PAVE PAWS radar. (The only exceptions were several measurements, all near the WCIB-FM station transmitting tower, where the power density was as high as 5.6 microwatts/cm$^2$.) Because of this great disparity, it is not productive to make further comparisons between the PAVE PAWS emissions and the existing ambient.

### B.3 PAVE PAWS EMR Field Measurements

#### B.3.1 Test Locations

The 26 August field measurements were made at four test sites in the far field of the south face of the antenna. Table B-1, p. B-3, gives the elevation above sea level and the distance and bearing from the radar antenna for each site. Figure B-1 is a map of the Otis AFB area showing the 26 August test site locations. The entire antenna face was plainly visible from sites 1 and 4.

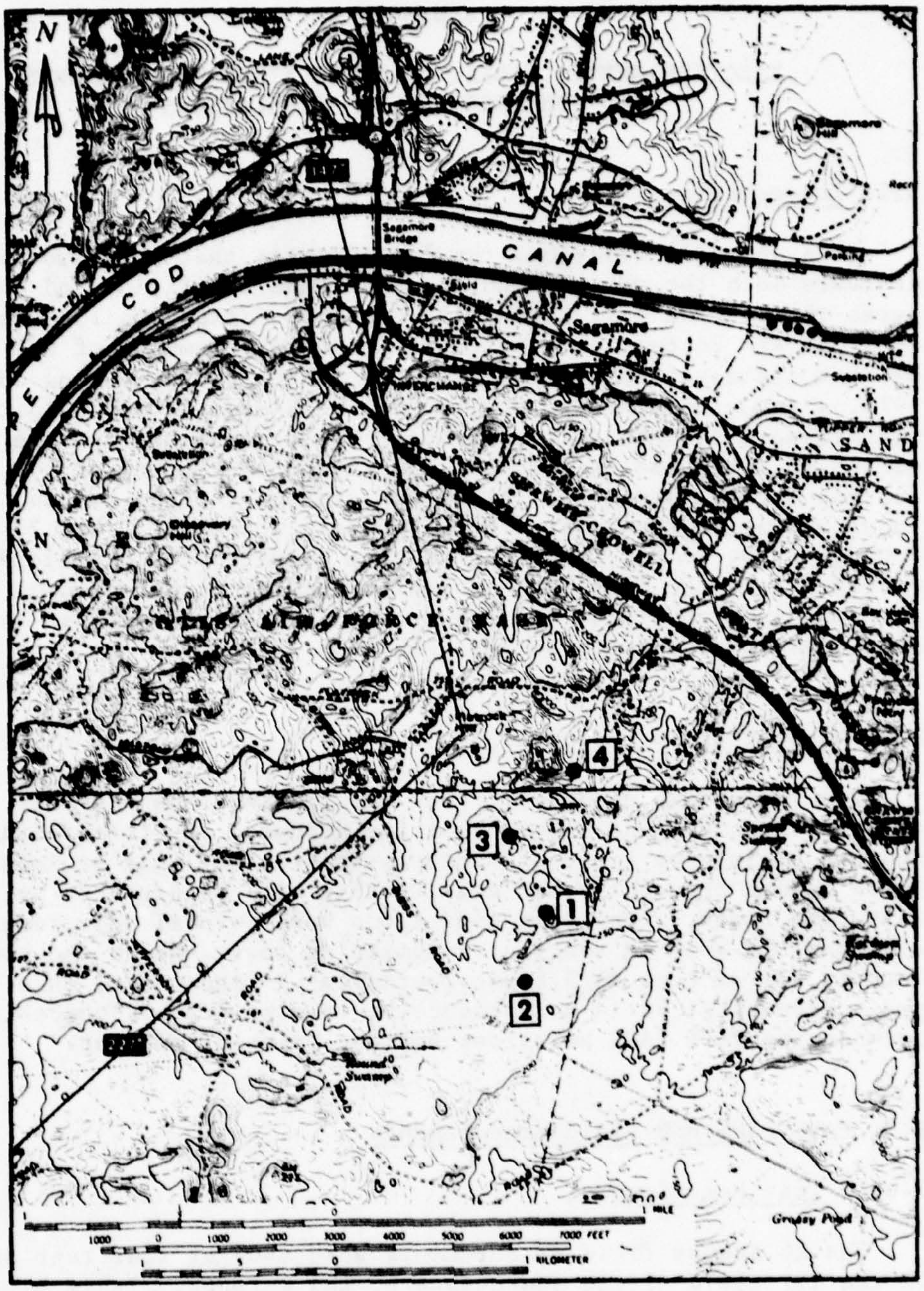


FIGURE B-1. 26 AUGUST 1978 EMR FIELD MEASUREMENT TEST SITE LOCATIONS

Table B-1

**SITE IDENTIFICATIONS**[a]
**(26 August 1978)**

| Site Number | Site Letter | Elevation (ft) | Distance (ft) | Azimuth |
|---|---|---|---|---|
| 1 | BR | 274 | 3,100 | 155 |
| 2 | B | 250 | 3,900 | 167 |
| 3 | A | 258 | 1,600 | 158 |
| 4 | AR | 230 | 1,800 | 104 |

[a]The elevation of the center of the radar face is 320 ft. Azimuth 167 is the boresight axis of the south face. These site identification numbers do not correspond to those used in Appendix A or Table B-5, p. B-13.

At sites 2 and 3 the antenna face was considerably obscured by trees. These sites are representative of the highest accessible spots in the area, which is moderately rough and heavily wooded.

On 4 October field measurements were made at a point near the exclusion fence, 1,000 ft northeast of the radar.

On 20 and 21 October field measurements were made at 21 test sites in the far field of the north and south face of the antenna. Table B-2 lists all the locations and the distance from the radar antenna for each site. Figure B-2, p. B-5, is a map of the communities near Otis AFB showing the 20 and 21 October test site locations.

On 20 October another team using different equipment made field measurements at many locations less than 500 ft away from the radar. The locations of these test sites with respect to the radar are shown in Figure B-4, p. B-14.

### B.3.2 Test Conditions

During the 26 August field measurements, the radar was operated in a single mode representative of enhanced surveillance at a 20% duty cycle. The duty cycle of the normal surveillance mode was 10% rather than 11%. The repetition rate of the surveillance mode was doubled during these tests to yield the 20% duty cycle noted. The elevation of the surveillance fence was set at 3, 6, or 10 deg at the request of the field measurements team. Radar operating parameters were recorded during each measurement.

++

Table B-2

SITE IDENTIFICATIONS[a,b]
(20-21 October 1978)

| Test Site[a] | Location | Elevation In Feet | Distance In Miles |
|---|---|---|---|
| 1 | Rest Area, Route 6 | 212 | 0.67 |
| 2 | Shawme and Shaker House Roads | 118 | 2.1 |
| 3 | Henry T. Wing School | 40 | 2.26 |
| 4 | Dillingham and Knott Roads | 62 | 2.36 |
| 5 | Sandwich High School | 132 | 4.22 |
| 6 | Entrance, Lakewood Hills Development | 155 | 4.48 |
| 7 | Knolltop and Greenhouse Roads | 139 | 5.44 |
| 8 | Mashpee Police Department | 104 | 7.8 |
| 9 | Mashpee Middle School | 60 | 9.93 |
| 10 | Seabury Golf Club | 60 | 15.0 |
| 11 | Sagamore Bridge | 255 | 1.62 |
| 12 | Canalside Apartments | 100 | 2.18 |
| 13 | Hoxie Elementary School | 65 | 1.79 |
| 14 | Old Plymouth Road | 100 | 2.78 |
| 15 | Hilltop Drive (Maiolini Residence) | 150 | 1.04 |
| 16 | Kieth Field | 20 | 1.46 |
| 17 | Stone School, Otis Air Force Base | 110 | 7.7 |
| 18 | Ashumet Development, Hatchville | 75 | 9.4 |
| 19 | Benthos Corp. | 55 | 9.7 |
| 20 | North Falmouth Elementary School | 50 | 9.9 |
| 21 | Falmouth High School | 65 | 13.0 |

[a]These test site numbers are not the same as those listed in Appendix A.

[b]Independent observer John Ohman of Sandwich calculated the distances and furnished the elevations, which were prepared by Mr. William Taylor, Town Engineer.

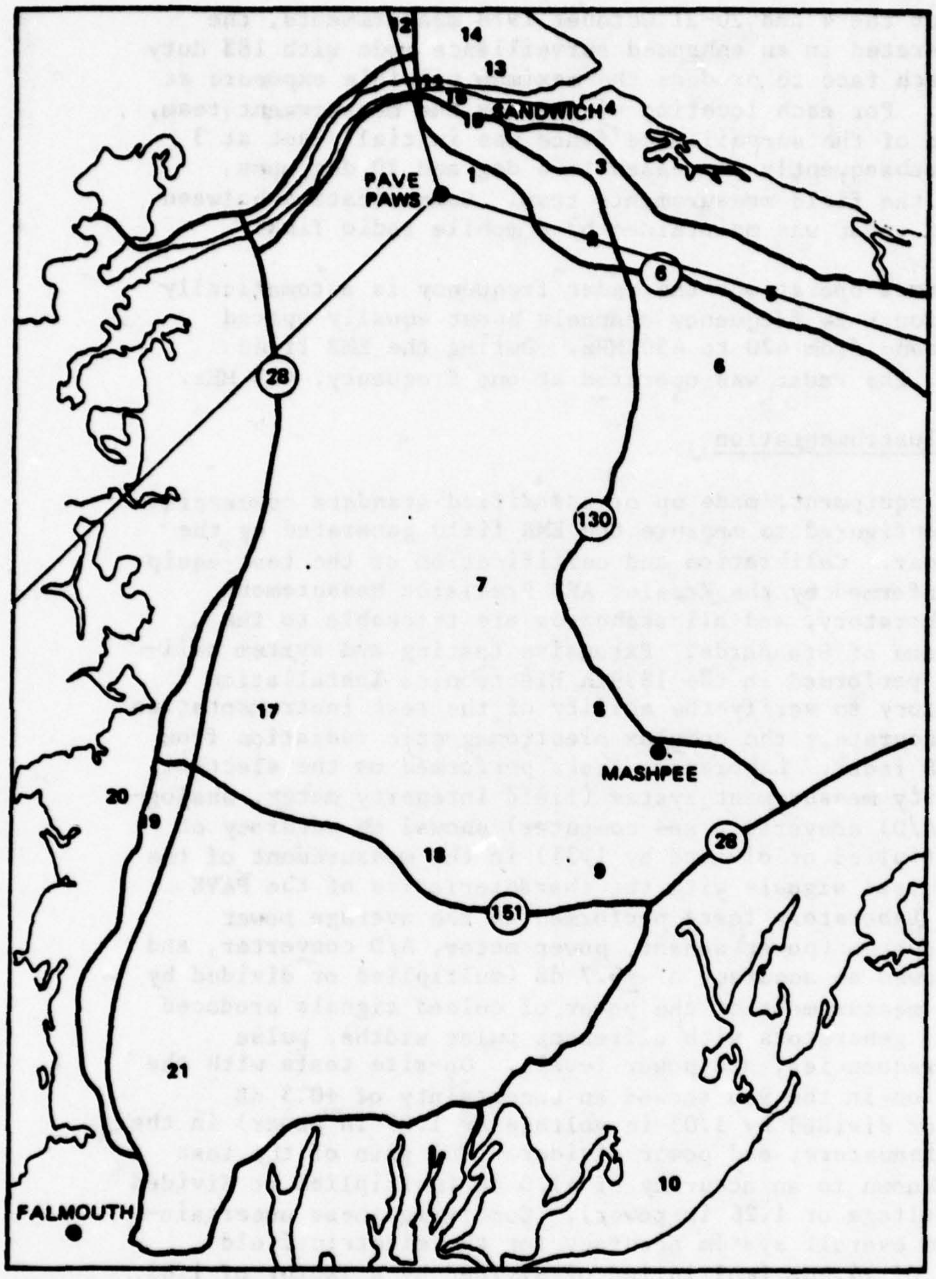


**FIGURE B-2. EMR FIELD MEASUREMENTS TEST SITE LOCATIONS (20 OCTOBER AND 21 OCTOBER 1978)**

Throughout the 4 and 20-21 October 1978 measurements, the radar was operated in an enhanced surveillance mode with 18% duty applied to each face to produce the maximum possible exposure at ground level. For each location visited by the measurement team, the elevation of the surveillance fence was initially set at 3 deg; it was subsequently increased to 6 deg and 10 deg upon request from the field measurements team. Communication between test site and radar was maintained by a mobile radio link. +

Under normal operations the radar frequency is automatically sequenced through 24 frequency channels about equally spaced through the band from 420 to 450 MHz. During the EMR field measurements, the radar was operated at one frequency, 435 MHz.

B.3.3 Test Instrumentation

The test equipment, made up of unmodified standard commercial items, was configured to measure the EMR field generated by the PAVE PAWS radar. Calibration and certification of the test equipment were performed by the Keesler AFB Precision Measurement Equipment laboratory, and all standards are traceable to the National Bureau of Standards. Extensive testing and system calibration were performed in the 1839th Electronics Installation Group Laboratory to verify the ability of the test instrumentation to measure accurately the complex electromagnetic radiation from the PAVE PAWS radar. Laboratory tests performed on the electric field intensity measurement system (field intensity meter, analog-to-digital (A/D) converter, and computer) showed an accuracy of $\pm$2.7 dB (multiplied or divided by 1.36) in the measurement of the voltage of pulsed signals with the characteristics of the PAVE PAWS radar. Laboratory tests performed on the average power measurement system (power sensor, power meter, A/D converter, and computer) showed an accuracy of $\pm$0.7 dB (multiplied or divided by 1.17) in the measurement of the power of pulsed signals produced by two signal generators with different pulse widths, pulse repetition frequencies, and power levels. On-site tests with the instrumentation in the van showed an uncertainty of $\pm$0.3 dB (multiplied or divided by 1.03 in voltage or 1.07 in power) in the RF cable, attenuators, and power divider. The gain of the test antenna was known to an accuracy of $\pm$1.0 dB (multiplied or divided by 1.12 in voltage or 1.26 in power). Combining these uncertainties yield an overall system accuracy for the electric field measurements of $\pm$4.0dB (multiplied or divided by a factor of 1.6), and an accuracy of $\pm$2.0 dB (multiplied or divided by a factor of 1.6) for average power density measurements. (The apparent contradiction in this statement results from the fact that power varies as the square of the electric field.)

The instrumentation shown in Figure B-3 was installed in a screened enclosure in the mobile van used for all the measurements in the survey, except on 4 October when different, but similar, + equipment was used. The screened enclosure prevented possible EMR +

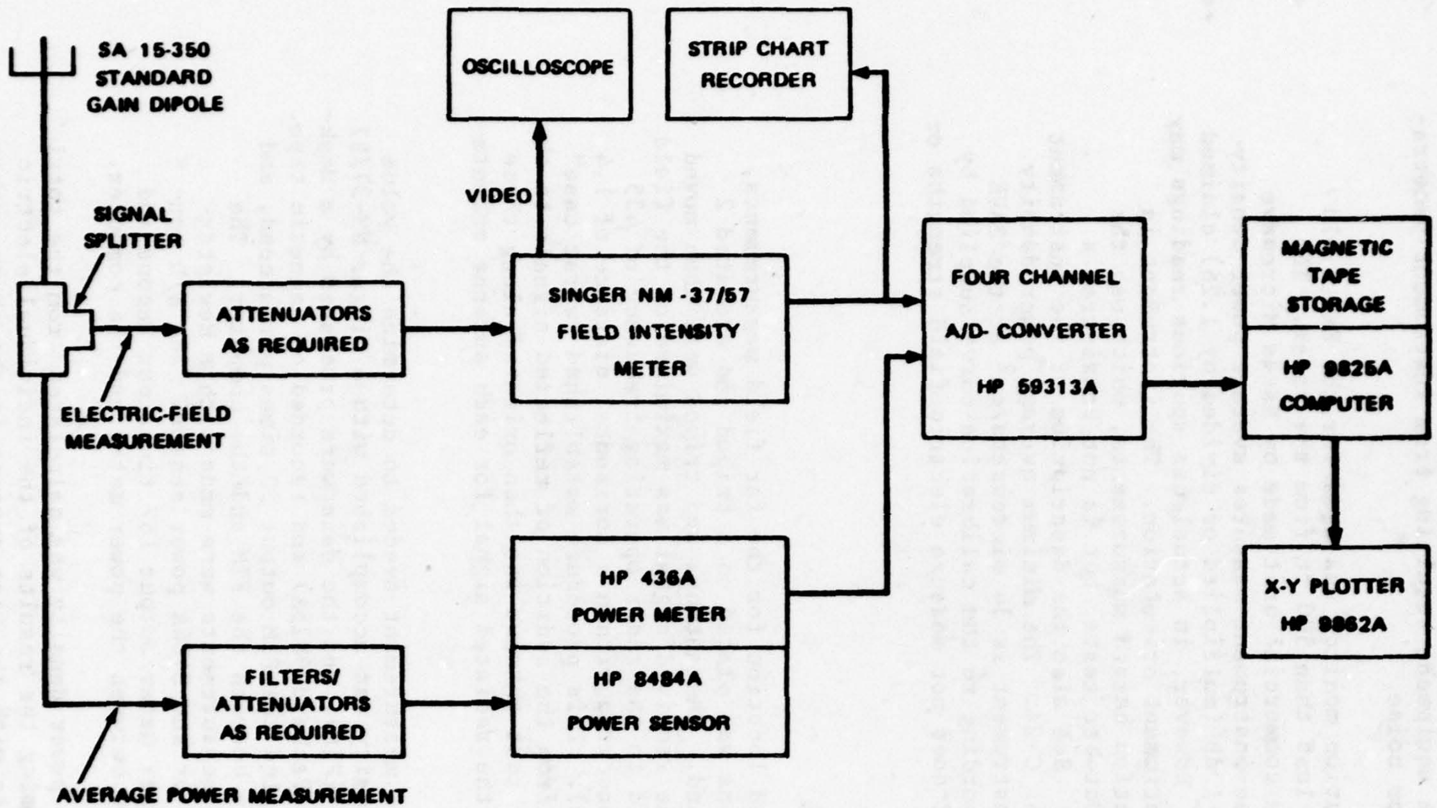


FIGURE B-3. TEST INSTRUMENTATION

interference with the equipment resulting from instrument penetration by EMR signals or noise.

A hand held radiation monitor was used for the EMR field measurements made at less than 500 ft from the radar. The instrument used was a commercial unit made by Narda Microwave Corp. Model 8616. The instrument measures average power density with an accuracy of ±1 dB (multiplied or divided by 1.26) claimed by the manufacturer. However, in actual use spurious readings may result because of instrument orientation. The instrument is widely used for radiation hazard measurements, which was the objective of the 20 October tests, but is not considered a precision instrument. See also the description of the instrument in Section C.6.2.1, p. C-24. The minimum average power density measurable by that instrument is 34 microwatts/cm$^2$ at the PAVE PAWS frequencies, according to the calibration curve supplied by the manufacturer. It does not measure electric field strengths or pulse power.

### B.3.4 Test Procedure

At each designated location for the far field measurements, the dipole test antenna was placed on a tripod and elevated 2 meters above the ground. The antenna and tripod were then moved horizontally until the received signal was maximized on the field intensity meter (tuned to the radar operating frequency of 435 MHz). This usually occurred within a horizontal distance of 1.4 meters (2 wavelengths). This procedure established "worst case" conditions resulting from the addition of reflected signals to the incident signal. The test antenna was then oriented along three orthogonal axes, and the radiated signal for each antenna orientation was measured.

The electric field measurement needed to determine the value of the pulse power density was accomplished with a Singer NM-37/57 field intensity meter (FIM), and the data were processed by a desktop computer (Hewlett-Packard 9825A) and recorded on magnetic tape. The A/D converter sampled the FIM output 50 times per second, and provided the interface between the FIM and the computer. The average power density measurements were made with a Hewlett-Packard 436A power meter and 8484A power sensor. The A/D converter sampled the power meter output 167 times per second and provided the interface between the power meter and the computer.

The total average power density was calculated from the total electric field by summing the results of the individual electric field measurements made with the test antenna in the three orthogonal orientations. This was done at each test location for each radar beam elevation measured. The total electric field was the vector sum of the individual orthogonal measurements (i.e., the square root of the sum of the squares of the three orthogonal

measurements). Measuring with the dipole antenna in three orthogonal planes was essentially the same as measuring with an isotropic (non-directional) antenna.

A total instrumentation verification was performed before and after the field measurements to validate the operation and accuracy of all test equipment and accessories.

### B.3.5 Results and Comparisons

Table B-3 lists the field values measured at the four locations on 26 August 1978. Table B-4, p. B-11, compares the measured field at 3 deg beam elevation angle with three sets of calculated values: those of Appendix A, values calculated by the method of Hankin (1977), and values corresponding to AF-ESD (1976). All of the calculated values have been adjusted to a 20% duty cycle and to the applicable distance and elevation so as to be directly comparable with the measured values. ++

Inspection of the values listed in Table B-4 shows that the estimates of field strength made by the AF-ESD are much greater than the measured values. The AF-ESD estimates were only intended to provide a rough approximation of the upper limit for the EMR field. The AF-ESD field model did not take into account terrain elevation variation and the correct relative strength of the secondary sidelobes; also the effect of beam motion was ignored.

Hankin, in 1977, prepared a much more detailed estimate of the PAVE PAWS EMR. Values for the electric field calculated by his methods are quite close to the measured values. However, average power densities estimated by his methods are generally about 10 times greater than measured values. Most of the difference results from underestimation of the power-reducing effect of beam motion. ++

Calculations of electric field intensity shown in Appendix A agree with those of Hankin. However, Appendix A estimates of average power densities are much lower than those of Hankin, and are close to the measured values. At all four sites the measured values of power density are lower than the predicted ones. At one location only (site 3), and only for the electric field, does a measured value exceed the calculated field, and then by a factor which is essentially identical with the uncertainty of the measurement. Because all of the measurements were made in the far field, where no approximations are used, the differences can only have been caused by local perturbations (reductions) of the actual EMR field. Such perturbations are readily attributable to attenuation by foliage, blockage of the line-of-sight to the radar, diffraction, or reflection from nearby objects or terrain irregularities.

Table B-3

PAVE PAWS EMR MEASUREMENTS, SOUTH FACE
(26 August 1978)

| Site | Beam Elevation (deg) | Electric Field (V/M) | Pulse Power Density (microwatts/$cm^2$) | Average Power Density (microwatts/$cm^2$) |
|---|---|---|---|---|
| | 3 | 20.2 | 108 | 0.87 |
| 1 | 6 | 14.6 | 57 | 0.37 |
| | 10 | 7.8 | 16 | 0.41 |
| | 3 | 13.4 | 48 | 0.38 |
| 2 | 6 | 8.1 | 17 | 0.20 |
| | 10 | —[a] | —[a] | —[a] |
| | 3 | 36 | 340 | 2.86 |
| 3 | 6 | 23.8 | 150 | 3.26 |
| | 10 | 23.6 | 148 | 2.90 |
| | 3 | 17.5 | 81 | 1.71 |
| 4 | 6 | 16.5 | 72 | 1.21 |
| | 10 | 12.5 | 41 | 1.11 |

[a] This run was not made because howitzer firing was scheduled to start at a nearby site.

Table B-4

COMPARISON OF MEASURED AND CALCULATED EMR

| Site | Distance (ft) | Electric Field (V/m) AF-ESD (1976) Calculated | Hankin[b] (1977) Calculated | Appendix A Calculated | 20 August 1978 Measured | Ratio[a] |
|---|---|---|---|---|---|---|
| 3 | 1,600 | 78 | 21.9 | 21.9 | 36.0 | 0.61 |
| 4 | 1,800 | 69 | 19.5 | 19.5 | 17.5 | 1.11 |
| 1 | 3,100 | 40 | 24.6 | 24.6 | 20.2 | 1.21 |
| 2 | 3,900 | 32 | 19.7 | 19.7 | 13.4 | 1.47 |

| Site | Distance (ft) | Average Power Density (microwatts/cm$^2$) AF-ESD (1976) Calculated | Hankin[b] (1977) Calculated | Appendix A Calculated | 20 August 1978 Measured | Ratio[a] |
|---|---|---|---|---|---|---|
| 3 | 1,600 | 222 | 23.7 | 3.76 | 2.86 | 1.31 |
| 4 | 1,800 | 174 | 18.6 | 3.00 | 1.71 | 1.75 |
| 1 | 3,100 | 58 | 10.1 | 2.65 | 0.87 | 3.05 |
| 2 | 3,900 | 37 | 6.6 | 1.70 | 0.38 | 4.47 |

[a]Ratio of Appendix A calculated to measured values. Ratios in the range 0.625-1.6 are consistent with the accuracy of measurement (see Section B.3.3, p. B-6).

[b]Calculated by Hankin's methods; see p. B-9

The time averaged power density measured on 4 October 1978 was 10 microwatts/cm$^2$ at a point near the exclusion fence about 1,000 ft northeast of the radar (Barone, 1978). That value may be compared with the calculated value of 15 microwatts/cm$^2$ at the same distance (Table A-9, p. A-37). ++

Table B-5 lists the field values measured at 21 locations in communities near PAVE PAWS on 20-21 October 1978. The values vary from less than 0.001 microwatts/cm$^2$ up to a maximum of 0.061 microwatts/cm$^2$. All of the measured values are less than the calculated values from Appendix A. Most of the test sites are not line-of-sight from the radar and therefore the measured values would not be expected to be comparable to the calculated values due to the effect of terrain and foliage blockage. +

The results of the near-field measurements made on 20 October are shown in Figure B-4, p. B-14. The measured values varied from 34 microwatts/cm$^2$ which was the minimum detectable average power density to a maximum of 2,000 microwatts/cm$^2$. The measured values do not exceed 100 microwatts/cm$^2$ at any point inside the security fence but outside the exclusion fence. The average power density was below the minimum detectable on all floors inside of the radar building. The presence of measurable power levels near the guard tower in a zone that is not scanned by either face of the radar is attributed to diffraction and scattering effects. All of the measured values inside the exclusion fence are less than those calculated in Appendix A. + ++

## B.4 Summary

Excepting only the site near the WCIB-FM station as mentioned in Section B.2, p. B-1, the EMR field strengths generated by the PAVE PAWS radar are large compared to the ambient fields that exist in the vicinity of the radar. The measured values of electric field and average power density radiated by PAVE PAWS have also been compared with predicted values; at all but one location measured values were lower than those predicted by the field model as described in Appendix A. At one location only, the measured electric field exceeded the calculated field by a factor of 1.64, which is essentially within the uncertainty of the measurement. Comparison of the measured and calculated values permits the conclusion that the field model developed in Appendix A is well founded and conservative.

## Table B-5 ++

### PAVE PAWS EMR MEASUREMENTS
(20-21 October 1978)

| Test Site[a] | Maximum Electric Field (V/m) | | Pulse Power Density (microwatts/cm²) | | Average Power Density (microwatts/cm²) | |
|---|---|---|---|---|---|---|
| | Calculated[c] | Measured | Calculated[c] | Measured | Calculated[c] | Measured |
| 1 | 9.65 | 8.57 | 24.7 | 19.5 | 0.79 | 0.061 |
| 2 | 4.35 | 3.18 | 5.0 | 2.7 | 0.15 | 0.027 |
| 3 | 4.04 | 0.46 | 4.3 | 0.055 | 0.13 | b |
| 4 | 3.87 | 3.70 | 4.0 | 3.6 | 0.12 | 0.02 |
| 5 | 3.42 | 0.42 | 3.1 | 0.047 | 0.05 | 0.001 |
| 6 | 4.07 | 0.15 | 4.4 | 0.006 | 0.05 | b |
| 7 | 3.75 | 0.31 | 3.7 | 0.026 | 0.04 | b |
| 8 | 2.62 | 0.09 | 1.8 | 0.002 | 0.02 | b |
| 9 | 2.05 | b | 1.1 | b | 0.01 | b |
| 10 | 1.36 | 0.09 | 0.5 | 0.002 | 0.005 | b |
| 11 | 11.0 | 4.44 | 30.5 | 5.23 | 0.37 | 0.051 |
| 12 | 4.13 | 2.79 | 4.7 | 2.07 | 0.14 | 0.016 |
| 13 | 3.61 | 0.89 | 3.5 | 0.209 | 0.11 | 0.001 |
| 14 | 4.03 | 0.84 | 4.3 | 0.188 | 0.19 | 0.002 |
| 15 | 6.20 | 1.14 | 10.2 | 0.345 | 0.33 | 0.003 |
| 16 | 4.43 | 0.17 | 5.2 | 0.008 | 0.16 | b |
| 17 | 2.66 | 0.08 | 1.9 | 0.002 | 0.021 | b |
| 18 | 2.17 | 0.09 | 1.2 | 0.002 | 0.014 | b |
| 19 | 2.11 | 0.06 | 1.2 | 0.001 | 0.013 | b |
| 20 | 2.96 | b | 1.1 | b | 0.013 | b |
| 21 | 1.58 | b | 0.6 | b | 0.007 | b |

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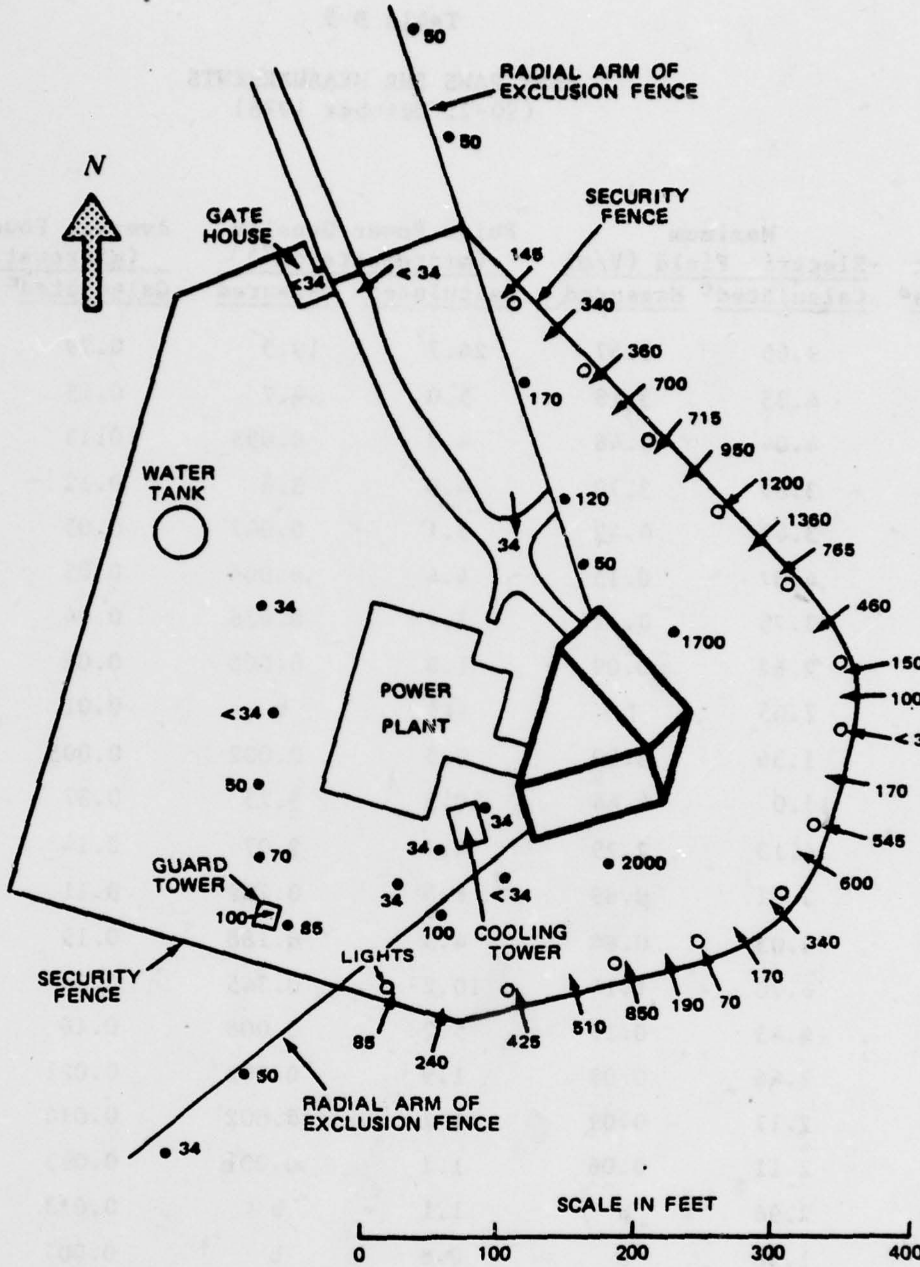
a These test site numbers correspond to those listed in Table B-2, p. B-4. They are not the same as those listed in Tables B-3 and B-4 or those in Appendix A.

b Below reportable levels (less than 0.001 microwatts/cm²).

c Calculated by the methods of Appendix A.




NOTE: READINGS IN MICROWATTS/CM$^2$ (SEE SECTION B.3.3, p. B-8 FOR LIMITATIONS ON ACCURACY). ALL MEASUREMENT LOCATIONS SHOWN ARE APPROXIMATE; NO POSITION MEASUREMENTS WERE MADE. ALL MEASUREMENTS WERE MADE AT GROUND LEVEL EXCEPT THE ONE IN THE GUARD TOWER.

FIGURE B-4. PAVE PAWS EMR MEASUREMENTS, 20 OCTOBER 1978 ++

## B.5 References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## Appendix C

## HUMAN EXPOSURE TO RADIOFREQUENCY RADIATION (RFR)

### C.1 Introduction

This appendix is written in the form of a detailed critical review, including a bibliography, of selected scientific articles from the published literature on RFR effects. It is recognized that in this form it may not be easily comprehensible to the interested layperson. A more readable form that parallels the organization of this appendix is provided in the basic EIS. The letter "C" in paragraph numbers in this appendix is equivalent to the paragraph number prefix "3.1.2.1" in the basic EIS. (Specific bibliographic references are not included in the basic EIS). ++

To provide uniformity of presentation and to improve the readability of this appendix, the generic term radiofrequency radiation (RFR) has been used to include other terms commonly found in the literature, such as electromagnetic radiation (EMR), nonionizing electromagnetic radiation (NIEMR), microwave radiation, electromagnetic fields (EMF), microwave fields, and others. The term RFR, as used here, is intended to apply to the frequency band from approximately 10 to 18,000 MHz (18 GHz). The PAVE PAWS frequency band is 420 to 450 MHz.

This appendix is organized as follows: In the Introduction (C.1), the problem (potential impact on human health of exposure to the PAVE PAWS field) is described, and the methods used to develop information pertinent to assessing the problem (data base selection and evaluation) are given. In the next section (C.2, p. C-5), a summary is given of the present situation as it exists in the United States with regard to RFR-emitting devices in general and to high-power radar systems in particular. Because there are many considerations, problems, and interdependent processes that usually are not explicitly stated as being an integral part of the hazard or risk assessment process, but which are vital to it, the following two sections (C.3, p. C-7, C.4, p. C-9) discuss the general problems involved, as well as those more specific to interpretation of scientific research in the context of the PAVE PAWS problem. The next section (C.5, p. C-12) catalogs recent reviews in the area of bioeffects of RFR. The present state of knowledge of physical mechanisms of interaction of RFR with biological entities and of field measurements is contained in the next section (C.6, p. C-15). The present state of knowledge of biological effects is described in a series of subject-specific

subsections of C.7, p. C-27. Following the review, there is a brief mention of major unresolved issues, namely the problem of determining exact equivalence between effects on animals and those on humans and the problems inherent in retrospective epidemiological studies (C.8, p. C-71). Sections C.9 and C-10, p. C-72, + refer the reader to the main body (Sections 3.1.2.1.9, p. 3-59, + and 3.1.2.1.10, p. 3-62) where all this information is integrated, + and it is concluded that the likelihood of adverse effects on human health from exposure to PAVE PAWS radiation is very small. A comprehensive bibliography comprises the last section (C.11, + p. C-73) of this Appendix.

+

### C.1.1 The Problem

The main question of concern in this appendix is whether ++ exposure to the RFR produced by PAVE PAWS is likely to produce a significant impact on human health. Two situations must be considered. First, people may be airborne in the vicinity of PAVE PAWS. In this event they may be exposed to the main beam and first sidelobe in addition to higher order sidelobes (see Appendix A for a complete description). Second, people at ground level outside the exclusion fence will be exposed to the higher-order sidelobes and, at some elevations and distances for the basic system only, the first sidelobe as well. (Possible exposure of individuals within the exclusion fence, e.g., military personnel, civilian employees, and visitors, is excluded from consideration because the Site Command will provide appropriate protective and control measures as required by the USAF Occupational Safety and Health program.)

### C.1.2 Airborne Exposure

Exposure of an airplane to the main beam is a possibility shared with many operational high-power radar systems. However, as far as is known, there is no medically-documented case of harm to humans from any such incidental exposure, and there is no reason to believe that the PAVE PAWS situation would be significantly different from that of other radar installations in this respect. The calculated maximum pulse power density on the axis ++ of the main beam of the basic system is approximately 560,000 microwatts/cm$^2$ for distances up to about 600 ft (the start of the transition region), and it diminishes to 300,000 microwatts/cm$^2$ at about 1,100 ft (within the transition region), to approximately 150,000 microwatts/cm$^2$ at 1,440 ft (the start of the far-field region), and to about 11,000 microwatts/cm$^2$ at 1 mile (see Section A.3.3.1, p. A-14). Corresponding pulse power densities for the growth system are approximately: 570,000 microwatts/cm$^2$ for distances up to about 1,200 ft (the start of the transition region); 300,000 microwatts/cm$^2$ at about 2,200 ft (within the transition region); 150,000 microwatts/cm$^2$ at 2,850 ft (the start of the far-field region); and 44,000

microwatts/cm$^2$ at 1 mile. The threshold for human perception of individual pulses as apparent sound is about 300,000 microwatts/cm$^2$ (see Section C.6.1.2, p. C-22). Therefore, a person within an aircraft that flies through the main beam would not hear individual pulses unless the aircraft is closer than approximately 1,100 ft for the basic system or 2,200 ft for the growth system, if it is assumed that the aircraft provides no attenuation and that the ambient noise level within the aircraft is negligible. In addition, there is no experimental evidence that such persons would experience effects ascribable to the pulse repetition rates per se (modulation effects) from exposures of the order of 1 minute (see below). In Section D.3.2.1.3, p. D-68, a model is presented to show the volume of airspace near PAVE PAWS containing surveillance mode main beam power density, the highest average power densities to which an aircraft could be exposed. That volume is within a few hundred feet of the ground, airspace not normally used by aircraft. The maximum average power density in that volume for the basic system is about 140,000 microwatts/cm$^2$ adjacent to the array faces, 270 microwatts/cm$^2$ at 1,440 ft from the radar, and about 20 microwatts/cm$^2$ at one mile from the radar. The values for the growth system in the surveillance volume are about 142,500 microwatts/cm$^2$ adjacent to the array faces, 270 microwatts/cm$^2$ at 2,850 ft, and 80 microwatts/cm$^2$ at one mile. Thus, aircraft flying closer to the radar in that volume could be exposed to average power densities between about 275 and about 142,500 microwatts/cm$^2$ for a few seconds at most, but the proximity of the ground and the radar building would constitute a physical hazard unacceptable to the prudent pilot. Aircraft penetrating that volume on the longest path, as shown in the referenced section, are exposed for less than a minute. Because of these considerations, the likelihood of a biological health hazard to persons in aircraft is considered negligible, and not given further attention in this assessment.

### C.1.3 Ground-Level Exposure.

For both the basic and growth systems, calculations indicate that the average power densities to which the general public may be chronically exposed ("general public exposure") are less than 1 microwatt/cm$^2$; field measurements indicate that the actual values are less than 0.1 microwatt/cm$^2$. Exposure to higher power densities for relatively brief intervals may occur for individuals who elect to approach the radar along the roads leading to the site or by traversing the off-road area up to the exclusion fence. Calculations for the basic system indicate that the maximum average power density at 1,440 ft along the ground is approximately 4 microwatts/cm$^2$ for Sectors 2 and 3 (defined in Figure 3-1, p. 3-3), and double that value (i.e., approximately 8 microwatts/cm$^2$) for Sector 1 in which the higher-order sidelobes from the two PAVE PAWS faces overlap. The distance from ++

1,440 ft to the exclusion fence, located 1,000 ft from the faces of the radar, includes part of the so-called transition zone of the radiated field. Power density increases linearly (approximately) in this region. At the 1,000-ft exclusion fence, the calculated maximum average power densities are approximately 30 microwatts/cm$^2$ in Sector 1 and approximately 15 microwatts/cm$^2$ in Sectors 2 and 3. The measured power density at 1,000 ft in Sector 2 was 10 microwatts/cm$^2$ (see Section B.3.5, p. B-12). Along the outside of the radial arms of the exclusion fence (Figure 3-9, p. 3-12), the average power density rises to 42 microwatts/cm$^2$ at 350 ft on the west security fence boundary and to 90 microwatts/cm$^2$ at 250 ft on the south security fence boundary (see Table 3-1, p. 3-11). These two distances correspond to the locations where the exclusion and security fences intersect, and they represent the points of closest possible public approach.

To determine pulse power densities, the highest values for ++
individual pulses were calculated rather than inferred from mean duty-cycle considerations. The results for the basic system are 460 microwatts/cm$^2$ in Sector 1 at 1,000 ft and 1,200 microwatts/cm$^2$ at the 250-ft point of closest public approach. Therefore, the latter value of pulse power density and 90 microwatts/cm$^2$ average power density were used for assessing whether the RFR from the basic PAVE PAWS system would be potentially hazardous to human health.

Similar calculations of power densities for the growth option
yielded the following values: At 2,850 ft, the maximum average ++
power densities are 4 microwatts/cm$^2$ for Sector 1, and 2 microwatts/cm$^2$ for Sectors 2 and 3. At the 1,000-ft exclusion fence the maximum average power density is 29 microwatts/cm$^2$ and at the 250-ft location of closest approach, the value is 160 microwatts/cm$^2$. The corresponding pulse power densities are 1,160 and 2,400 microwatts/cm$^2$, respectively. Thus, the latter value of pulse power density and 160 microwatts/cm$^2$ average power density were taken as the maxima at ground level for the growth system.

### C.1.4 Data Base and Literature Selection

A variety of sources was used in the acquisition of a working data base for this assessment. These sources included: reference bibliographies provided in previous reviews of the literature (C.5, p. C-12); the comprehensive bibliography of Glaser (1976, 1977); published proceedings of recent seminars and meetings on the biologic effects of RFR (Tyler, 1975; Czerski, 1974a; NATO, 1975, Johnson, 1976; Justesen, 1977; Hazzard, 1977); the computerized data base on Biological Effects of Electromagnetic Radiation (BEER file) of the Mead Technology Corporation, Dayton, Ohio; and the compilations of articles published by the Franklin Institute

(1978). Consideration was also given to recent symposia (Abstracts, Airlie, 1977; Abstracts, Ottawa, 1978; Abstracts, Helsinki, 1978), whenever the abstracts contained sufficient detail on procedures and results to allow reasonable evaluation.

Articles were selected from the above data base for inclusion in this review by several criteria, such as: date of publication, frequency band of the radiation (preferably, close to that of PAVE PAWS, but also other frequencies in the general range 10 MHz to 18 GHz), significance to human health (e.g., long-term exposure of animals and humans, the latter including epidemiology studies and reports of congenital defects), previous recognition of a paper as significant, possible relevance to concerns expressed by citizens' groups, or because the article helps to complete the overall picture provided by a series of other articles. Because of the large number of references in this general research area, the number of articles selected was necessarily limited, but it is representative of the total.

### C.1.5 Eastern European Bioeffects Literature

Although there are many translations available of Eastern European research on the bioeffects of RFR that were published in the 1960s, many of these are difficult to assess critically because important details are lacking.

Starting with the World Health Organization- (WHO-) sponsored Warsaw Conference (Czerski, 1974a) held in 1973, there has been an increase in scientific exchange between the United States and Eastern European countries on the bioeffects of RFR. This has resulted in an increasing number of Eastern European research reports in Western publications in a style that is amenable to critical review. These reports, together with those available in translation through the Joint Publications Research Service, have been considered for inclusion in this appendix. Criteria for selection of Eastern European publications were the same as those discussed in Section C.1.4 of this appendix, and the Eastern European literature constitutes approximately 15% of the bibliography.

## C.2 Present Climate and Context

PAVE PAWS has been introduced in a general climate of widespread proliferation and usage of RFR-emitting devices and systems. Demand for the services and facilities of these devices is reflected by the following figures for the United States (McRee, 1978). During 1976, sales of communications and electronics products are estimated to have totalled $38 billion. The FCC, as of 1977, had authorized transmissions by over 9 million

transmitters. Between 1971 and 1978 there was an increase of 87% in the number of FM stations operating in the 88-108 MHz band. The National Institute of Occupational Safety and Health (NIOSH) has estimated that there are over 35 million industrial RF sources for heating and drying in use in the plastics, paper, and other industries. Approximately 5 million microwave ovens are presently installed in homes in the United States (McConnell, 1978). There are presently on the order of 30 million citizen band (CB) radios licensed, with those operating in the 27 MHz band capable of emitting up to 4 watts. There are also many thousands of mobile radios, each permitted to radiate at up to 110 watts, that are specifically licensed for the frequency band 470-512 MHz, adjacent to the PAVE PAWS operational band. Domestic and business satellite communications systems are burgeoning. Air and maritime navigation makes widespread use of fixed and mobile radar systems. Thus, there exists a widespread climate of acceptance of the benefits of RFR devices for communications, radar, and industrial processes. On the other hand, there are those who question ++
whether the proliferation of usage of RFR devices may be associated with some as-yet undefined hazardous biological effects. It is the purpose of the present document to address such concerns.

The RFR from PAVE PAWS may be compared with the fields from existing military and defense radar systems. Many of the high-power search and height-finder radars that comprise the U.S. early warning system have been operating continuously (except for routine maintenance) for years. Recently, Air Force personnel conducted a survey of RFR levels in the area surrounding and on North Truro Air Force Station, Massachusetts (U.S. Air Force, 1978b). Three high-power early-warning-system radars are operational on the base: an AN/FPS-107 search radar, an AN/FPS-26A height finder radar and an AN/FPS-6 height finder radar. More than 65,000 data points were recorded during the survey at 44 different test locations. Locations were previously recommended by EPA and also by the local citizens' groups. The radar units were positioned so that the maximum ground level radiation intensities would be recorded. Results of this survey yielded time-averaged power densities of less than 10 microwatts/cm$^2$ at all but 4 test locations. Two of these four sites were on base and yielded measurements of 42 and 19 microwatts/cm$^2$. The other two sites located adjacent to the base yielded measurements of 25 and 20 microwatts/cm$^2$. The majority of the measurements were less than 1 microwatt/cm$^2$. These measurements are quite comparable with those already made, or those calculated for the environs of the PAVE PAWS radar. The measured maximum pulse power densities +
at the same four sites where average power densities exceeded +
10 microwatts/cm$^2$ ranged from 194,000 to 369,000 micro- +
watts/cm$^2$. Questions concerning the impact on human health of +
PAVE PAWS may therefore justifiably be viewed in the context of impacts, or lack thereof, on human health at and around existing defense high-power radar facilities, and in the general context of

scientific evidence of hazards, or lack thereof, resulting from the widespread usage of RFR devices in society today.

### C.3 Problems of Risk Assessment

The assessment of risk to human health and the setting of standards to protect it is an extremely complex problem. In addition to purely technical and scientific questions, there are problems of philosophy, law, administration, and feasibility of programs that are still only vaguely recognized. It is clearly beyond the scope of this document to deal with those subjects in detail, but it is important that they be mentioned. The present section will concentrate on three problems relevant to the present issue: the scope of biological effects considered in setting standards, the overall approach to setting standards, and standards of protection from microwave radiation in the United States and the USSR.

The problem of choosing biological effects to consider and determining the acceptable degree of risk or undesirable effect can be illustrated by comparing occupational air pollution standards prevailing until recently in the USSR and the United States (Zielhuis, 1974). In the USSR, maximum allowable concentrations (MACs) for airborne noxious agents are set at a value that will not produce any deviation from normal in physiological parameters, or any disease in anyone exposed (occupational or general population). In the United States, threshold limit values (TLVs) for airborne noxious agents are set at a level such that nearly all workers can be exposed regularly during the working day without adverse effect. The differences stand out clearly: in the USSR, all biological effects are considered without regard to medical significance or possibility of human adaptation, and the level of protection must extend ideally to the most susceptible member of the population. In the United States, only harmful effects are considered, and protection of the susceptible workers is generally excluded, except that a safety factor is generally included in the TLV such that an adverse reaction in an individual can be detected before serious medical consequences ensue.

Both of the approaches in the preceding paragraph are predicated on the existence of a threshold concentration; that is, on a concentration below which no biological effect will occur. In the absence of a true threshold, one is faced with absolute choices about the level of protection to give to the population versus the cost and technical feasibility of that protection. These choices are the foundation of risk/benefit analysis in the assessment of environmental hazard. The subject of the existence or nonexistence of thresholds has been debated at length, but much of the debate has been conducted at a level of opinion rather than fact. As a practical scientific matter, thresholds for noxious or deleterious effects must exist at least for some substances, because

many naturally-occurring substances are essential to life at one concentration and highly toxic at higher concentrations (Horne, 1972). In this document, the possibility of threshold levels for RFR effects is considered on a case-by-case basis, with due regard for the physiological mechanisms of effect.

The overall approach to standard-setting can be considered in terms of the conservative (Lowrance, 1976) versus the liberal (Stokinger, 1971) approach. The principal distinction in the two viewpoints is that the conservative approach is strongly concerned with the danger of noxious agents that may have long-term irreversible effects, while the liberal approach is more concerned with practical problems in dealing with agents that have immediate and well-recognized deleterious effects. The difference is primarily a matter of assignment of priorities, but when taken to extremes, the difference can lead to unrealistic or scientifically unsupportable positions on the presence or absence of human hazard from environmental pollution. Analysis of hazards from RFR in this document takes the liberal position in matters of scientific proof of real or potential biological effects and a conservative position in matters of potential consequences of effects, particularly those effects that are likely to be irreversible.

Safety standards for occupational and general exposure in various countries are cited in terms of average power densities (or free-space-equivalent electric and magnetic field intensities), permissible exposure durations, and frequency ranges of applicability. In the USSR (which has the lowest permissible levels), the maximum permissible occupational power densities in the frequency range from 300 MHz to 300 GHz for exposure to stationary antennas are 10 microwatts/cm$^2$ for a full working day, 100 microwatts/cm$^2$ for 2 hours, and 1,000 microwatts/cm$^2$ for 20 minutes; the values for rotating antennas are 100 microwatts/cm$^2$ for a full working day and 1,000 microwatts/cm$^2$ for 2 hours (Stuchly, 1978). The maximum value for continuous (24-hour) exposure of the general population is 5 microwatts/cm$^2$ (Shandala, 1978). The principles on which the standard was developed are not known to us. Presumably the principle of no effect in any person (Zielhuis, 1974; Baranski, 1976) was applied, together with other considerations. Soviet armed forces are specifically exempt from this standard (Stuchly, 1978). There is no official standard for RFR exposure in the United States, but the American National Standards Institute has set a radiation protection guideline for occupational exposure of 10,000 microwatts/cm$^2$ averaged over any 6 minute period (Stuchly, 1978), and recommends that the limit not be exceeded "without sound reason." This guideline has been adopted by Department of Labor's Occupational Safety and Health Administration (OSHA) and the DOD.

In the analysis of the possible biological effects of radiation from the PAVE PAWS facility, the health and well-being of the

population living in the vicinity is considered to be of primary importance. The basis for decision is the presence or absence of documentable evidence of harmful effects at maximum public exposure to PAVE PAWS radiation levels that may be produced by the facility. Existing or contemplated exposure standards are not at issue, and do not form the basis for any of the recommendations contained in this document. Further elaboration of details of RFR protection standards in many countries is given in Stuchly (1978).

## C.4 Assessment of Scientific Information

In an assessment of the potential biological effects of PAVE PAWS RFR, certain quantitative relationships must be considered among (1) the physical parameters of the RFR such as frequency, power density, polarization, and pulse characteristics; (2) the mechanisms of absorption and distribution of energy within the biological organism; and (3) the resultant biological effects as measured by some functional or anatomic alteration. Like all scientific theory, the body of biophysical theory that links these three factors has been synthesized from a variety of experimental evidence. The theory is dynamic, in that it is subject to refinement or revision as further valid evidence accumulates that is inconsistent with the current theory. Nevertheless, the present theory furnishes the context in which new experimental evidence is considered. +

Experimental evidence comes from the observation of experimental animals and, sometimes, of humans who have been exposed to RFR. The physical characteristics of the radiation, the mechanisms of interaction, and the biological response are known in some cases, at least qualitatively. Obviously, the most directly applicable experimental evidence relative to possible bioeffects of PAVE PAWS would be from experiments in which humans were exposed to the specific frequency, waveform characteristics, and power density values that are calculated to emanate from PAVE PAWS. Further, it would involve quantitative evaluation of a large number of biological endpoints. Such data, however, do not exist. The available information is indirect because it is derived primarily from experiments with animals and therefore requires at least some extrapolation among species, field characteristics, duration of exposure, and biological effects.

The usual experiment involves the exposure of groups of animals to a single frequency, either continuous wave or at a given pulse schedule. Each group is exposed under a combination of a specific power density and exposure time. It should be noted, + however, that magnetrons were used as microwave power sources in + many of the experiments reported in the literature, and that most + magnetrons operate in the pulsed mode, although frequently this + point is not mentioned. It is not uncommon, therefore, to find + studies in the literature in which the RFR used might be taken as +

CW when pulsed RFR was actually used. In the present context, the uniqueness of the radiation characteristics of PAVE PAWS (frequency, waveform, and power densities) renders all known experimental evidence indirect as it relates to the exposure parameters.

Retrospective epidemiologic studies are those in which the data are acquired after the event to be studied has occurred. While the subjects of such studies are, by definition, human and thus might furnish direct evidence from a species standpoint, epidemiologic evidence remains indirect, for two reasons. Not only are the exposure parameters unlike those predicted for the PAVE PAWS facility, the exposure parameters for most epidemiologic studies are not known with sufficient precision. In addition, the selection of an appropriate, unexposed control group of people, ideally identical to the exposed population in every respect except for the exposure itself, is practically impossible in the absolute sense. Since the conclusions of epidemiologic studies are almost always based upon comparisons between so-called matched populations, the extent to which the control population actually matches the experimental one becomes a critical matter in assessing the validity of the conclusions.

Regardless of the particular line of evidence being considered, certain concepts and constraints affect the interpretation of the evidence. In particular, there is disagreement as to whether an effect, especially one that is reversible or can be compensated, constitutes a hazard. Only rarely is any specific experimental study subjected to confirmation through the performance of an identical experiment by another investigator. More often, an analogous -- but not identical -- experiment is conducted with the objective of clarifying or expanding the results of the initial experiment. Thus, the second experiment ideally provides a better means of incorporating the findings into the theory that forms the body of knowledge in a particular field of investigation.

Still another consideration is also important: scientific findings are probabilistic in nature, in that facts are known only to some level of probability for a given population; applicability of those facts to a specific individual may be constrained. For example, the median effective dose for a certain agent describes the dose that will elicit the response characteristic of that agent in one-half of the exposed individuals. Before the dose is administered, however, it cannot be predicted whether any specific individual will respond. (Nonetheless, the prediction that any specific individual will have a 50% chance of showing the response is valid.) In effect, the probabilistic nature of scientific evidence means that there are no scientific data on which a guarantee of absolute safety for any individual or group of individuals can be based. There is disagreement as to whether the conventional scientific approach, whereby an investigator finds or fails to find a statistically significant (very low probability of

chance occurrence) difference between experimental and control groups, is appropriate to considering potential hazards to humans. The scientist's statement that no statistically significant differences between the groups are discernible is not equivalent to the absolute statement that there is no difference between the groups. Thus, no scientific evidence can provide proof that any agent is safe in the absolute sense.

Sometimes the magnitude of the difference in response between experimental and control populations is small. Biological studies designed to detect such a small, statistically significant difference require large numbers of animals and, in some cases, long exposure times. Therefore, the resources necessary to perform such studies are very large. Often the expenditure in time and money reaches the point where sponsoring institutions with limited budgets may decide that such studies are not cost-effective, in view of their overall objectives. As a frequent alternative, predictions of effects at very low levels are made from extrapolation of findings at higher levels, on the basis of assumptions about the mathematical relationship between the level (or dose) of the agent and the degree of the effect. Such assumptions are open to challenge, however, so this approach frequently leads to disagreement over the matter of whether there is a threshold below which no effects of the agent exist.

It must also be remembered that scientists, like everyone else, have personal values, goals, and attitudes. It has been said that there is no such thing as an unbiased expert, since to become an accepted authority involves a personal commitment and dedication over a period of time, which leads to emphasis of a certain viewpoint. Thus, like the probabilistic nature of scientific findings, objectivity may well apply to scientists as a group, but not necessarily to any individual scientist. Personal bias can consciously or unconsciously affect how the experiment is designed, how the data are interpreted, and, particularly, the applicability of the results to decision-making. The latter is especially important when the decision to be made is in an area outside the scientist's field of expertise.

Finally, scientific experiments are usually restricted, almost by definition, to the evaluation of only one factor. The real world, however, does not involve the operation of only one factor. The contributions of other factors, for example, is illustrated in the case of uranium miners, who show an increase in incidence of lung cancer that is presumed to result from inhalation of radioactive material associated with their occupation. The extent of the increase in nonsmoking miners is marginal, but miners who smoke cigarettes show a much larger increase in lung cancer than in either nonsmoking miners or the general population. Thus, any given scientific evidence can only supply probabilistic information that is relatively narrow when applied to the real world.

## C.5 Other Assessments and Reviews

Two other assessments of PAVE PAWS and nine representative general reviews, including two by Eastern European authors, are described in this section. All have been published between 1972 and the present. These reviews were used as a resource to identify relevant articles in the literature and as a means of assuring that the scientific literature was adequately covered for preparing the EIS. The conclusions and opinions of the authors of the assessments and reviews were considered and compared to those in the EIS; however, since each document was developed from a different viewpoint concerning RFR effects, the conclusions stated in the EIS and this Appendix were independently derived, explicitly considering the problems posed by the PAVE PAWS facility.

The Assembly of Life Sciences of the National Academy of Sciences appointed the Panel on the Extent of Radiation from the PAVE PAWS radar system to examine the levels of RFR to which the public may be exposed. In April 1979, the Panel released its report (NAS, 1979), entitled "Analysis of the Exposure Levels and Potential Biologic Effects of the PAVE PAWS Radar System." The report covers essentially the same topics as those addressed in the EIS, including: the RFR levels of PAVE PAWS to which the general population may be exposed, the various biological effects of RFR in animals, and reported effects of RFR in humans. The destinction between an effect and a hazard is made, and the difficulties of risk assessment are discussed, including the lack of adequate epidemiological studies. For discussing the biological effects of RFR, an average power density of 1,000 microwatts/cm$^2$ was selected as the arbitrary boundary between "high-intensity" and "low-intensity" effects. A total of 170 references are cited, many of which are the same as those in the EIS or which include comparable information. A general conclusion was that exposure of humans to low-intensity RFR can have effects, but that on the basis of current information, the known or suspected effects are reversible and not associated with increased morbidity or mortality. The specific conclusion with regard to PAVE PAWS is quoted below.

> "In conclusion, the PAVE PAWS radar may be anticipated to expose a limited number of members of the general public intermittently to low intensities of pulse-modulated microwave fields with maximal instantaneous intensities of 100 microwatts/cm$^2$ or less and time-averaged intensities lower by two orders of magnitude. There are no known irreversible effects of such exposure on either morbidity or mortality in humans or other species. Thus, it is improbable that exposure will present any hazard to the public. In view of the known sensitivity of the mammalian CNS to electromagnetic fields, especially those modulated at brainwave frequencies, the

possibility cannot be ruled out that exposure to PAVE PAWS radiation may have some effects on exposed people. Because these effects are still hypothetical, it is not feasible to assess their health implications. Such assessment will require additional research and surveillance and must be addressed in future evaluations of the potential exposure effects of PAVE PAWS and other high-power-output radar systems."

Another assessment written specifically for PAVE PAWS is that by the Radiobiology Division, USAF School of Aerospace Medicine (U.S. Air Force, 1978a), entitled "Biologic Judgments in Support of PAVE PAWS Environmental Assessment." Some 173 references are cited. Sections of the review discuss the Air Force RFR research program, epidemiologic studies concerning DoD personnel, chronic and acute studies of animals, effects of pulsed radiation versus those of CW radiation, review papers, and a section on "Opinions Related to Special Interest Questions" (the latter raised in a letter from Congressman Studds to the Air Force). The special interest questions are those concerning the Moscow Embassy; congenital abnormalities; effects on the immune system, behavior, flora and fauna; electromagnetic interference with cardiac pacemakers; interaction with biological media; effects on brain tissue and neurochemistry; and U.S. exposure standards versus those in the USSR. +

+

The nine reviews that follow are presented with the most recent first. +

Two reviews, one covering RFR biophysics and the other discussing biologic and pathophysiologic effects of exposure to RFR, are contained in the transactions of a short course held in Ottawa, Canada, in June 1978. Lin (1978) presents an assessment of the current knowledge about RFR interactions with biological systems, with emphasis on the dielectric properties of tissue materials, propagation and absorption of RFR in tissues, and basic physical mechanisms of interaction. There are 76 references cited. +

Michaelson (1978), after reviewing fundamental principles related to biomedical research in the laboratory and extrapolation to man, discusses topics including the concept of scaling, cellular effects, chromosomes, genetic effects, growth and development, the gonads, neuroendocrine response, effects on the nervous system, cardiovascular effects, hematopoiesis, effects on immunity, the auditory response, cataractogenesis, epidemiologic and incidence studies, and interference with implanted, electronic cardiac pacemakers. Michaelson provides 209 reference citations.

Stuchly (1977) reviews potentially hazardous RFR sources, citing 38 references. The review discusses those sources judged to have potential for producing hazardous levels of RFR under normal operating conditions and under possible malfunction, and considers satellite communications systems, radar systems, communications systems, and microwave-power devices for generating heat. +

Dodge and Glaser (1977) assess international trends in research, development, and occupational health and safety, concentrating on events since 1975. Some 25 references are cited. Sections discuss exposure standards, research on bioeffects, effects of RFR on humans, and U.S. Federal RFR health and safety programs.

Cleary (1977) provides a critical review of the results of 12 studies on various aspects of biological effects of RFR. Also included are references to 100 other articles. Sections of the review discuss physical characteristics of RFR, RFR absorption in biological and model systems, effects of nonuniform RFR absorption, and a major section on physiological effects of RFR exposure. The latter includes hematopoietic effects, neuroendocrine effects, and RFR effects on pathogenic organisms. Also included are RFR/drug interactions, effects on sensory organs, effects on + reproduction and development, cellular and subcellular effects, neural effects, effects on excitable cell systems. Additional consideration is given to behavioral effects, molecular interactions, dosimetry, and standards for human exposure.

Carpenter (1977) gives a critical, comprehensive presentation of RFR and its effects, emphasizing RFR as an environmental agent. Sections deal with physical characteristics and properties of RFR, effects on tissue, "thermal" and "nonthermal" effects (see + definitions in Section C.6.1, p. C-15), exposure levels, + biological effects of RFR on human beings and experimental animals, as well as RFR effects on the eye, the testes, the nervous system, and on development. Carpenter cites 110 references.

Baranski and Czerski (1976) have published the most comprehensive compilation and discussion of the literature to date. The 234-page book contains references to 614 articles, with wide representation given to both Eastern European and Western + studies. Chapters include an introduction, physical characteristics of RFR, interactions of RFR with living systems, biological + effects of RFR (experimental data), the health status of personnel occupationally exposed to RFR (symptoms of microwave overexposure), safe exposure limits and prevention of health hazards, and final comments.

Sudakov and Antimoniy (1973) provide an extensive review (224 references) of the neurophysiology and behavior of animals and humans, in an English translation of the original Russian article

by the Joint Publications Research Service. The authors appear to accept as uncontestable the premise that RFR has direct effects (denoted by them as "nonthermal") upon the nervous systems of animals. The review is in two main sections. The first is concerned with biological aspects of the effects of RFR on the central nervous system (CNS) of animals and man, and contains subsections on natural RFR as a factor in evolution, the effects of natural RFR on animals and man, RFR on the activity of the CNS, the sensing of RFR by living organisms, and the effects of RFR on the behavior and conditioned activity of animals and man. The second main section is concerned with neurophysiological mechanisms of action of RFR, with subsections on bioelectrical activity of the brain during exposure to RFR, morphological and functional changes in the CNS upon exposure to RFR, and selective action of RFR on structures of the CNS.

Milroy and Michaelson (1972) review information available until that date on RFR cataractogenesis. They include 59 references. Sections include animal experimentation, discussion of experimental data, human studies, discussion of human data, and conclusions.

## C.6 Present State of Knowledge Regarding Physical Effects

### C.6.1 Interactions of Fields with Biological Entities

Interactions of electromagnetic fields with biological entities are often loosely characterized in the bioeffects literature as "thermal" or "nonthermal," a usage that has led to confusion and controversy. Therefore, it is appropriate at this point to introduce working definitions of these terms, with the recognition that the boundary between these types of interaction is not sharp.

The interaction of an agent (e.g., RFR) with an entity (biological or nonbiological) can be characterized as thermal if the energy absorbed by the entity is transformed at the absorption site into heat. Heat absorption, in turn, is defined in classical thermodynamics as either an increase in the mean random speed (or kinetic energy) of the molecules at the site (a local increase in temperature), or as an increase in the disorder or randomness of the molecular motion without an increase in mean random speed (a first-order phase change), or both.

An entity can also absorb energy at specific discrete frequencies in the form of energy packets or "quanta," each of which has an energy proportional to one of the discrete frequencies. The constituents and configurations of the various molecular species comprising the entity determine the specific frequencies or characteristic spectra at which such absorption can

occur. The kinds of interactions involved are numerous and of varying degrees of complexity. They include alterations of molecular orientations and configurations that do not change the basic identities of the molecules, disruption of intermolecular or intramolecular bonds, and excitation of atoms or molecules to higher electron states (including ionization). Such interactions can be characterized as "short-range" processes. There are also cooperative interactions among subunits of molecules within biological cells, in cell membranes, and in extracellular fluids. Cooperative interactions are often characterized as "long-range" because absorption of energy at one specific site in a structure, e.g., in a membrane or in a biological macromolecule, can affect a process elsewhere in the structure, or a function of the structure as a whole can be triggered by the release of energy stored in the structure, thereby producing biological amplification.

Conceptually, all such quantum interactions can be characterized as "nonthermal". However, if most of the energy thus absorbed is subsequently transformed locally into heat (as defined above), the distinction between "nonthermal" and thermal is blurred. Pragmatically, therefore, characterization of an interaction of RFR with a biological entity as nonthermal requires that the interaction give rise to a frequency-specific effect that is experimentally distinguishable from heating effects due to thermalization of the absorbed RFR energy.

#### C.6.1.1 Thermal Effects of Time-Averaged Power Density and Dose-Rate Considerations; Nonthermal Effects of CW RFR ++

Consider now the effects of CW RFR on a human or an animal. The relative magnetic permeability of most organic constituents is about unity. Therefore, thermal interactions (as defined above) can be described in terms of the dielectric, electrical-conductivity, and thermal properties of the bodily organs, tissues, fluids, and so forth, as well as the characteristics of the RFR (frequency, power density, polarization). Measurements of these properties have been made for various mammalian tissues, blood, cellular suspensions, protein molecules, and bacteria over the spectral region from about 10 Hz to 20 GHz, notably by Schwan and coworkers (Schwan, 1963, 1957; Schwan and Piersol, 1955; Schwan and Li, 1953) and others (Lin, 1975; Cook, 1951, 1952). In general, the dielectric constants were found to vary inversely with frequency in a separate characteristic manner for each of three parts of that frequency range ("alpha," "beta," and "gamma" dispersion regions), ascribable to different predominant relaxation mechanisms, each characterized by specific time constants (Schwan, 1957). In the low and intermediate frequency ranges (about 10 Hz to about 100 MHz), encompassing the "alpha- and beta-dispersion" regions, the properties of cell membranes, which have large specific capacitances (about 1 microfarad/$cm^2$), predominate. In the range above about 10 GHz

("gamma-dispersion" region), membrane impedances are negligible, and the behavior of the water and electrolyte content are most predominant. As an example of the large numerical variation of dielectric constant, the values for muscular tissue decrease by five orders of magnitude, from about $3 \times 10^6$ at 10 Hz to 30 at 20 GHz.

In the frequency range from about 300 MHz to about 10 GHz, the dielectric constants of skin, muscle, and blood vary little with frequency because the transition between the beta- and gamma-dispersions occurs in this range. The mean dielectric constants for these three constituents are about 40, 50, and 60, respectively; the differences in values are largely ascribable to the proportion of water in each constituent, water having a dielectric constant of about 80.

Because the index of refraction of any material is related to its dielectric constant, electromagnetic fields are reflected and refracted at the air-surface interface and at internal boundaries between constituents of widely different dielectric properties, e.g., at interfaces between the skull and the dura or between a body cavity and adjacent tissues, thereby affecting the internal field distributions. At 450 MHz, for example, about 65% of the incident power density is reflected at the air-skin interface (Johnson, 1972), and the approximately 35% that enters the body is progressively attenuated with depth because of energy absorption.

The attenuation constant (rate of energy absorption with distance) of any material is proportional to the square root of its electrical conductivity. The concept of "penetration depth" (inverse to attenuation constant) is often used. For homogeneous specimens, the penetration depth is defined as the distance at which the electric field amplitude is $1/e$ (37%) of its value or the power density is $1/e^2$ (14%) of its value just within the surface. The electrical conductivities of skin, muscle, blood, and other constituents of the body increase slowly with frequency up to about 1 GHz and rapidly from about 1 GHz upward. At about 450 MHz, the penetration depth for muscle (and blood) is about 3 cm, and it is about six times greater for fat. (At about 10 GHz and higher, field penetration is largely confined to the skin.) In the literature on bioeffects of RFR, thermal energy absorption from an electromagnetic field is usually characterized by the Specific Absorption Rate (SAR), defined as the rate of energy absorption in a small volume at any locale within an entity, divided by the mean density of the constituents in that volume. SAR is expressed in terms of W/kg or mW/g. The numerical value of SAR in any small region within a biological entity depends on the characteristics of the incident field (power density, frequency, polarization) as well as on the properties of the entity and the location of the region. For biological entities that have complex shapes and internal distributions of constituents, spatial variations of SAR are not readily calculated. Therefore, the

concept of "mean SAR," which represents the spatial average value for the body per unit of incident power density, is often used because it is a quantity that can be measured experimentally--e.g., by calorimetry--without requiring information on the internal SAR distribution.

Many investigators have studied relatively simple geometric models, including homogeneous and multilayered spheroids, ellipsoids, and cylinders that have weights and dimensions approximately representative of various species, including humans. Such models were actually, or were assumed to be, irradiated with linearly polarized plane waves to determine the dependence of mean SAR on frequency and orientation relative to the polarization direction of the RFR. Many of the significant data have been included in a compendium (Durney et al., 1978) that is useful for very approximate frequency-scaling and interspecies comparisons of mean SAR values. An important result of this work is that the largest value of mean SAR is obtained when the longest dimension of each kind of model is parallel to the electric component of the field and when the wavelength of the incident RFR is about 2.5 times the longest dimension. The adjective "resonant" is often applied to the frequency corresponding to this wavelength. The resonant value of mean SAR for each model is also inversely dependent on the dimension perpendicular to the polarization direction (and propagation direction) of the field, i.e., the model has characteristics somewhat similar to those of a lossy dipole antenna in free space. Resonances would also occur for circularly polarized RFR. Such RFR can be resolved into two mutually perpendicular components, each having half the total power density. Therefore, an entity exposed to circularly polarized RFR would have lower resonant mean SAR values than it would have if exposed to linearly polarized RFR of the same total power density.

Based on prolate-spheroidal models (and linearly-polarized RFR), the resonant frequency for an "average" man, approximately 5 ft 9 in tall (1.75 m) and weighing about 154 lb (70 kg), is about 70 MHz; at this frequency the mean SAR is about 0.2 W/kg for 1,000 microwatts/cm$^2$ incident power density, or about 1/6 of his resting metabolic rate, or about 1/21 to 1/90 of his metabolic rate when performing exercise ranging from walking to sprinting (Ruch and Patton, 1973). Similarly, the resonant frequency for an "average" woman about 5 ft 3 in tall is about 80 MHz, and her mean SAR is about the same as for the average man. The resonant frequency of a 10-year old is about 95 MHz; for a 5-year old, about 110 MHz; and for a 1-year old, about 190 MHz. The resonant mean SAR values for such children are about 0.3 W/kg for 1,000 microwatts/cm$^2$. The presence of a ground plane or other reflecting surfaces shifts the resonant frequencies downward and can produce higher values of mean SAR at the lower resonant frequencies (Gandhi et al., 1977; Gandhi, 1975).

The foregoing discussion of mean SAR is also largely applicable to pulsed RFR (and other types of modulated RFR) at corresponding carrier frequencies and time-averaged incident power densities. (However, as discussed in the next section, there are several differences in interaction between CW and pulsed RFR.)

To illustrate how the concept of mean SAR can be interpreted, consider the resonant value for the model man (0.2 W/kg for 1,000 microwatts/cm$^2$ at 70 MHz). Exposure of such a model man to 100 microwatts/cm$^2$ average power density at 70 MHz for about 1 hr in the absence of any heat-removal mechanisms would produce a mean temperature rise of 0.02°C. Exposure to the same power density for the same duration, but at frequencies in the PAVE PAWS range would produce considerably smaller increases in mean temperature. If reflecting surfaces are nearby, then the PAVE PAWS frequencies are further from resonance, which compensates at least partially for the higher mean SAR at the downward-shifted resonant frequency. (The resulting numerical values of mean SAR in the PAVE PAWS frequency region would depend on the specific nature and configuration of the reflecting surfaces).

On the basis of such mean SAR considerations, it can be concluded that chronic exposure of humans (<u>in vivo</u>) to the RFR from PAVE PAWS at the average power densities outside the exclusion fence at ground levels (see Section C.1.3, p. C-3) is most unlikely to cause any rise in mean body temperature.

Homogeneous and multilayered spheroidal and cylindrical experimental models, having appropriate electromagnetic and thermal characteristics to represent various parts of the body, such as the head and limbs, have been studied as well (Wu and Lin, 1977; Neuder, 1976; Kritikos and Schwan, 1976; Lin, 1976; Kritikos and Schwan, 1975; Weil, 1975; Joines and Spiegel, 1974). The primary objective of the studies has been to determine the internal spatial field distributions created by linearly-polarized plane waves. Probably the most significant findings for spherical head models have been the discoveries of local regions of relative maximum SAR values and the manner in which the locations of such regions depend on the size of the head, the electromagnetic characteristics of its layers, and the wavelength of the incident field. These regions have been conveniently dubbed "hot spots," even for combinations of incident power density and exposure duration that would produce biologically insignificant temperature rises at such spots. As representative examples of such findings, two multilayered spherical head models with diameters of 10 and 20 cm were analyzed (Kritikos and Schwan, 1976). For the 10-cm head, the hot spots are internal over the frequency range from about 400 MHz to about 3 GHz; the highest relative maximum SAR occurs at about 1 GHz. Above and below that frequency range, the hot spots are at, or just within, the surface facing the field source (front surface). At 450 MHz, the hot spot is close to the front surface and its SAR is about 15% larger than the front-surface hot-spot

SAR at 400 MHz. By contrast, for the 20-cm head (about the diameter of an adult human head), there are no deep internal hot spots at any frequency; the hot spots are always at or just beneath the front surface.

Results of theoretical analyses of simple geometric models have been verified experimentally by (1) constructing physical models from synthetic biological materials (having approximately the same electromagnetic characteristics as their corresponding biological constituents), (2) exposing such models to sufficient power densities to obtain readily measurable temperature rises, and measuring such rises in temperature immediately after irradiation. Although much useful information has been obtained from models that have relatively simple geometries, human and animal configurations are far more complicated and different from one another. Therefore, SAR distributions in animal carcasses and figurine-shaped physical models have been determined experimentally (Gandhi et al., 1977; Guy et al., 1976a). Calorimetry has been used to measure whole-body mean SAR values (Kinn, 1977; Hunt and Phillips, 1972). A widely used technique to determine internal field distributions is to section a carcass or physical model along appropriate parting planes, then reassemble and expose it. The spatial temperature distribution over each parting plane is then measured with scanning infrared thermography immediately after exposure. However, such spatial temperature distributions should not be regarded as the corresponding in vivo internal temperature distributions, because the heat-transfer characteristics of such carcasses and physical models are significantly different from those of live animals and do not have the thermoregulatory mechanisms of the latter. Instead, such measured temperature distributions represent approximations to the internal field or SAR distributions.

Among the qualitative results of general interest with human figurines is that at frequencies near resonance, the local fields can be much higher for certain regions, such as the neck and groin, than for other body locations. In addition, field distributions for nonprimates are quite different from those for primates; this is a point that should be given proper consideration when the analyst attempts to extrapolate experimental findings on any laboratory animal species to humans, or to compare experimental results on different laboratory species.

Regarding quantum interactions of CW RFR, the activation energies for short range effects at the molecular level extend from about 0.08 eV ($1.3 \times 10^{-20}$ J) for hydrogen-bond disruption to about 10 eV ($1.6 \times 10^{-18}$ J) for ionization. The corresponding quantum frequencies range from about 19 to 240 THz (1 THz = $10^3$ GHz) (Cleary, 1973). However, an electromagnetic quantum at 450 MHz has an energy of only $1.8 \times 10^{-6}$ eV ($2.9 \times 10^{-25}$ J), or approximately 0.00002 of the energy required for hydrogen-bond disruption, which is at the lower end of the

energy-activation range previously cited. Therefore, the existence of nonthermal biological effects of CW RFR ascribable to such short-range molecular interaction mechanisms is extremely doubtful.

Biological generation of fields having frequencies in the ELF range (below 100 Hz) such as the EEG is regarded as evidence for the occurrence of cooperative or long-range interactions. Several theoretical models of neuronal membranes (e.g., Schmitt and Samson, 1969; Frohlich, 1975a; Frohlich, 1975b; Grodsky, 1976) indicate that activation energies or frequencies for cooperative processes can be much lower than those for short-range interactions. Because the thermal energy corresponding to the physiological temperature 37°C is about 0.027 eV, corresponding to a spectrum that encompasses the quantum frequency range for cooperative processes, the question has been raised whether postulated effects of weak RFR on cooperative processes, based on theoretical models, would be distinguishable from effects that are spontaneously induced thermally. Alternatively, separation of such RFR interactions from those thermally induced may require that the rates of occurrence of the former exceed the rates for the latter. This requirement implies that for manifestation of such effects of RFR, the intensity of the incident field must exceed minimum values or thresholds related to the specific processes. Because predictions from various theoretical models and related considerations conflict to a significant extent (see Adey and Bawin, 1977b; Taylor and Cheung, 1978), the issue of whether weak external fields at frequencies well below the infrared range (i.e., RFR) can alter biological processes is not yet resolved. However, *in vitro* effects ascribed to such cooperative processes have been reported, notably field-induced increases and decreases of calcium-ion binding to cell membranes of isolated neonate chick brains, a phenomenon called "calcium efflux" (irrespective of the direction of the change). Specifically, lower calcium efflux was reported for chick-brain hemispheres excised, incubated in physiological solution, and exposed to fields in the ELF range than similarily treated but unexposed hemispheres (Bawin and Adey, 1976b). This phenomenon was not observed with CW (unmodulated) RFR at 147 MHz (Bawin, Kaczmarek, and Adey, 1975) or at 450 MHz (Bawin, Sheppard, and Adey, 1978); however, higher calcium efflux was reported for brain hemispheres exposed to ELF-modulated RFR at these carrier frequencies, as discussed in the next section.

### C.6.1.2 Interactions of Pulsed RFR and Nonthermal Effects ++

Precise usage of the term CW RFR implies the presence of only a single frequency (and unvarying incident power density). Because of the time variations of power density and frequency in pulsed RFR (and other forms of modulation), possible biological effects ascribable to the pulse characteristics per se must also be considered.

The temperature rise of any given region within a biological entity due to the arrival of a single RFR pulse would be small, because of the relatively large thermal time constants of biological materials and the operation of heat-exchange mechanisms. However, if the region contains a boundary between layers of widely different dielectric properties, then the temperature gradient (rate of change of temperature with distance) can be large at such a boundary even though the mean temperature rise of the region is small.

One single-pulse effect known to occur *in vivo* is the phenomenon of "microwave hearing" (Frey, 1961) (discussed also in Section C.7.5.1, p. C-43), or the perception of single or repetitive short pulses of RFR as apparently audible clicks. In human volunteers subjected to pulsed fields at 3 GHz, pulse durations of the order of 10 microseconds and longer and minimum peak power densities of 300,000 microwatts/cm$^2$ were needed for perception (Cain and Rissman, 1978). The interaction mechanisms involved are not yet completely understood. However, almost all of the experimental results tend to support the theory that pulse perception occurs because of transduction of the electromagnetic energy into sound pressure waves in the head and normal detection by the auditory apparatus. In one group of suggested mechanisms, transduction is postulated to occur at a boundary between layers having widely different dielectric properties (e.g., at the boundary between the skull and the skin or dura). The energy in a pulse arriving at such a boundary is converted into an abrupt increase in momentum that is locally thermalized, producing a negligible volumetric temperature rise but a large temperature gradient across the boundary. Under such conditions, rapid local differential expansion would occur, giving rise to a pressure (sound) wave. This effect is often characterized as nonthermal because the power density averaged over two or more pulses can be miniscule. For example, consider two successsive pulses, each 20 microseconds in duration and having 1,000,000 microwatts/cm$^2$ pulse power density (i.e., values well above the threshold). The time-averaged power density would be proportional to these values but inversely proportional to the time interval between the arrival of the pulses at the perceiver. This interval could be indefinitely long without affecting the perception of each pulse. Therefore, the time-averaged power density has no relevance to perception. Irrespective of how the microwave-hearing phenomenon is characterized, the significant point is that the preponderance of experimental evidence indicates that the pulses are converted into actual sound in the head, rather than perceived by direct RFR stimulation of the auditory nerves or the brain.

This phenomenon should not be a source of concern about PAVE PAWS because the pulse power densities at ground levels outside the PAVE PAWS exclusion fence are less than 1,200 microwatts/cm$^2$ for the basic system and 2,400 microwatts/cm$^2$ for the growth system, or at least two orders of magnitude lower than the thresholds for human perception.

Periodically pulsed RFR constitutes a particular type of amplitude-modulated RFR in which the pulse repetition rates are the primary modulation frequencies. Biological effects ascribable to modulation frequencies per se (as distinguished from those caused by individual pulses) have been postulated. The occurrence of such effects would require demodulation and filtering of the pulsed RFR, by the biological entity, to yield the modulation frequencies. Although postulated nonlinear interaction mechanisms (e.g., Adey, 1975b; Adey and Bawin, 1977b) are conjectural, the aforementioned results on calcium efflux from neonate chick brains exposed to ELF-modulated 147 MHz or 450 MHz RFR (and the absence of this effect for unmodulated RFR at these frequencies), reported by Bawin and coworkers, are regarded as experimental evidence for the occurrence of modulation effects. These results are relevant to PAVE PAWS (especially those with modulated 450 MHz RFR) because the pulse repetition rates of PAVE PAWS are approximately the same as the modulation frequencies used by them. In brief, the calcium efflux reported for chick-brain hemispheres exposed to 147 MHz modulated at frequencies between 6 and 20 Hz was higher than reported for control hemispheres. The incident average power density was 800 microwatts/cm$^2$, and the effect was largest at 16 Hz. Higher calcium efflux was also obtained with 16 Hz-modulated 450 MHz RFR at incident average power densities in the range from 100 to 1,000 microwatts/cm$^2$ but not below or above this range, indicating the existence of a power-density "window." Preliminary results of increased calcium efflux from the cerebral cortex of the paralyzed awake cat exposed to 16 Hz-modulated 450 MHz RFR at an incident power density of 375 microwatts/cm$^2$ were reported (Bawin et al., 1977c). Irrespective of the interaction mechanisms involved, there is no evidence that similar effects would occur in humans exposed to the basic system at ground levels outside the exclusion fence because the time-averaged power densities are below the average power densities for the chick-brain or preliminary cat-brain results.

This statement is also applicable to the growth system beyond the 1,000-ft exclusion fence, to the region along the entire northwest radial arm of the exclusion fence, and to the segment of the southwest radial arm from 1,000 ft to about 325 ft, where the calculated average power density is below 100 microwatts/cm$^2$ (the lower limit of the power-density window for the chick-brain results). Along the southeast radial arm segment from about 325 to 250 ft (the point of closest public approach), the calculated average power density increases to 160 microwatts/cm$^2$, a value that is within the power-density window for the chick-brain results but is less than the 375 microwatts/cm$^2$ for the cat-brain results. Thus, these results to date do not permit adequate assessment of whether similar effects would occur in humans from exposure to the RFR from the growth system in this small area. However, measurements on the basic system in this small area have indicated actual levels only 60% of the calculated values.

## C.6.2 Radiofrequency Radiation (RFR) Instrumentation and Measurements

### C.6.2.1 Instrumentation

Much of the early laboratory research on bioeffects of RFR suffered from lack of adequate instrumentation for measuring incident fields or energy absorption rates (e.g., as internal temperature rises at high incident levels) within biological entities. Moreover, the available instrumentation was often incorrectly used, or was the source of significant errors in numerical values, or of spurious biological findings (artifacts) traceable to perturbations introduced by the presence of the sensors. For these reasons, many of the early results should be viewed as questionable, at least from a quantitative standpoint. During recent years, however, major advances have been made in instrumentation, both for determining incident-field intensities for biological research, and for determining internal energy-absorption rates.

Considering first the instrumentation for determining incident fields, a representative device for measuring average power densities is the commercially available broadband isotropic monitor (Aslan, 1972). Its sensors consist of linear arrays of thermocouple elements, each array comprising a lossy antenna of relatively small length and capable of adequate response over the frequency range from 300 MHz to 18 GHz, for which a calibration curve is provided by the manufacturer. Isotropic response is obtained by incorporation of three mutually-perpendicular sensor arrays. To minimize errors in the direct-current output values of the sensor assembly caused by possible induction of spurious RF currents in the lead wires, the wires used are of very high resistivity (about 60 kilohms/ft). Also, the sensors are only lightly coupled to the incident field, so that perturbations of the field caused by scattering are minimal. The sensors respond to the mean-square of only the electric component of the field. Nevertheless, the use of the instrument for measuring average power densities in the far-field region is fully justified because the ratio of the amplitudes of the electric and magnetic components has essentially the same value (377 ohms, the "impedance" of free space) at all points in that region, and the instrument is calibrated to read total average power density. (In the near-field region of an antenna, it is necessary to measure the intensities of both the electric and magnetic components.) The most sensitive model of this instrument has a full-scale range of 200 microwatts/cm$^2$.

A more recently developed instrument is the National Bureau of Standards (NBS) Model EDM-2 Electric Energy Density Meter, designed for the 10-to-500 MHz range (Belsher, 1975; Bowman, 1973). Its sensor consists of three mutually perpendicular integral dipole-diodes ("rectennas") that also respond only to the electric component of the field. An 18-inch handle from the

sensor contains high-resistivity lead wires to minimize field perturbation and spurious pickup. The most sensitive range of the instrument is 0.003 microjoules/$m^3$ full-scale (equivalent to approximately 176 microwatts/$cm^2$), and its response time (rise time plus fall time) is about 1 ms in this range.

Field survey instruments of this kind have been analyzed for possible sources of error (Wacker and Bowman, 1971). Because of relatively long response times of such instruments, they cannot be used for measuring the pulse power densities of short pulses. Therefore, in research programs on possible bioeffects of pulsed fields, incident pulse power densities are usually calculated from measurements of average power density and duty cycle (or pulse duration and pulse repetition frequency), made with commonly available and readily calibrated components and instrumentation. The use of sophisticated equipment for directly measuring pulse heights (or instantaneous pulse power densities) at low average power densities, such as the NBS-referable calibrated instrumentation employed for measuring the fields from PAVE PAWS, is the exception.

Magnetic-field probes have been developed for relatively low frequency ranges, as exemplified by the two devices developed at NBS for near-field measurements in the Industrial, Scientific, and Medical (ISM) bands within the range from 10 to 40 MHz (Greene, 1975). The probes consist of single-turn, balanced-loop antennas of 10-cm and 3.16-cm diameter for the amplitude ranges 0.5 to 5 A/m and 5 to 50 A/m, respectively. (The free-space equivalent power density is proportional to the square of the amplitude. For example, the power density equivalents to 0.5 and 5 A/m are approximately 10,000 and 1,000,000 microwatts/$cm^2$, respectively.) ++

The development of assemblies of electric dipoles and magnetic loops for simultaneously measuring both components in the near field for frequencies below 300 MHz was reported from Poland (Babij and Trzaska, 1976).

Recent developments of implantable or insertable probes for measuring RFR-induced temperature changes or local fields within biological entities during exposure have largely diminished the problem of perturbation of the temperature or local field caused by the sensor and its lead wires. They have also reduced the magnitude of readout errors caused by electromagnetic pickup in the lead wires and by spurious potentials at junctions between sensors and lead wires. Examples of such progress include the miniaturized isotropic dipole-diode probe developed and evaluated by Bassen and coworkers (Bassen et al., 1977; Bassen et al., 1975) and the liquid-crystal/fiber-optic probe developed by Johnson and coworkers (Johnson et al., 1975). However, the relevance of such developments to PAVE PAWS is indirect, because temperature changes caused by the power densities from PAVE PAWS will be immeasurable in biological entities, even at so-called hot spots. This brief

mention is included here because such devices are expected to be more widely used in future research, even though they were not available or used in most of the bioeffects research to date.

Developmental efforts are also underway toward reducing errors and artifacts in the measurement, during exposure, of biologically generated fields and potentials such as the EEG and the EKG, as exemplified by the recently-reported work from the USSR (Tyazhelov, 1977a).

### C.6.2.2 Measurements of RFR Power Densities in Selected Cities

The Environmental Protection Agency (EPA) is measuring environmental values of field intensity at selected locations within various U.S. cities. A recent report (Tell and Mantiply, 1978) discusses the results for 12 cities (a total of 373 sites). The field intensities were measured at 6.4 m (21 ft) above ground at each location. Site selections in each city were based on the use of the population figures for the 1970 census enumeration districts in a manner that would permit estimations of cumulative fractions of the total population exposed at or below various power-density levels.

The frequency ranges covered (Janes, 1977) were: 0.5 to 1.6 MHz (standard AM-radio broadcast band), 54 to 88 MHz and 174 to 216 MHz (VHF-TV bands), 88 to 108 MHz (FM-radio broadcast band), ca. 150 and ca. 450 MHz (land-mobile bands), and 470 to 890 MHz (UHF-TV band). A separate antenna of appropriate design was used for each of the 7 bands. However, data taken in the 0.5 to 1.6 MHz band were not included in the analyses because that band is below the 10-MHz lower frequency limit of the U.S. radiation protection guide.

The measured average power densities, integrated over the frequency bands included in the analyses (i.e., from 54 to 890 MHz), ranged from about 0.001 to 2.5 microwatts/cm$^2$ (Athey, 1978); the FM band is the major contributor. Because many sources (ranging from 11 in Las Vegas to 43 in Los Angeles) contribute to the total power density at any given site, the site values measured in each city were used in conjunction with the corresponding census figures to obtain an estimate of the population-weighted median exposure value for that city, with the meaning that half of its population is being exposed at or below that power density (assuming a static population distribution). These median exposure values range from 0.002 microwatts/cm$^2$ (for Chicago) to 0.020 microwatts/cm$^2$ (for Portland, Oregon); the population-weighted median for all 12 cities is 0.0053 microwatts/cm$^2$. Also calculated were the cumulative population percentages exposed to higher (and lower) values than the medians, with the conclusion that approximately 99% of the population studied are exposed to 1 microwatt/cm$^2$ or less, or conversely, that 1% are potentially being exposed to greater than 1 microwatt/cm$^2$.

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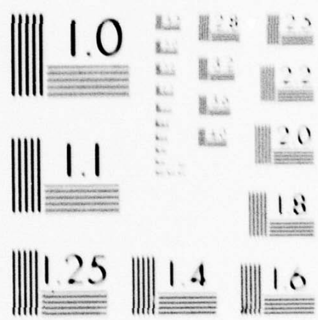
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1.4
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The relevance of these studies to PAVE PAWS is indirect; i.e., the measured power densities of such urban sites are of interest for purposes of comparison; however, the calculations of power densities and their verification by field measurements, discussed in other sections of this document, provide more direct and accurate data for analyses of population exposure to the RFR from PAVE PAWS than the method used by EPA. ++

## C.7 Present State of Knowledge Regarding Biological Effects

### C.7.1 Epidemiology

Ten recent reports based on epidemiologic evidence that bear some relevance to the PAVE PAWS evaluation in one or more respects are presented here. Although none of them involved exposure to a well specified RFR or to fields similar to those predicted for PAVE PAWS, they represent recent available epidemiologic information on exposure to RFR. Only three specify the frequencies involved, and estimates of power densities are provided only in some cases.

There have been two reports concerned with the relationship between Down's syndrome and exposure of the father to radar emissions. The initial report, entitled "Radiation Exposure in Parents of Children with Mongolism (Down's Syndrome)," by A. T. Sigler, A. M. Lilienfeld, B. H. Cohen and J. E. Westlake was published in the Bulletin of the Johns Hopkins Hospital, in Vol. 117, pp. 374-399 (1965). The data came from Baltimore Hospital records and interviews with parents. The major thrust of this report concerned the association between parental exposure to RFR and mongolism, but noted that 63.1% of the mongolism fathers had been in the military, as compared with 56.6% of the control fathers, and that 8.7% of the mongolism fathers and only 3.3% of the control fathers reported intimate contact with radar both in and outside of the armed forces, a difference that was statistically significant. The study involved 216 mongoloid children and 216 control children matched for hospital of birth (or at home), sex, date of birth, and maternal age at birth, and covered the period from January 1946 to October 1962. The authors concluded that "the only truly puzzling association is the suggested relationship between Mongolism and paternal radar exposure," and that "one can only speculate concerning possible mechanisms, but the association between Mongolism and radar exposure deserves further investigation." ++

Referring to the initial study as the Original Series, B. H. Cohen, A. M. Lilienfeld, S. Kramer, and L. C. Hyman published a second report entitled "Parental Factors in Down's Syndrome--Results of the Second Baltimore Case-Control Study" in Population Genetics-Studies in Humans, E. B. Hook and I. H. Porter, Eds., Academic Press, N.Y. 1977. The data from the ++

Original Series were considered with the data for an additional 128 matched pairs (Current Series). More detailed questions about radar/microwave exposure and military service were incorporated in the Current Series questionnaires and service record information on the fathers was acquired. An attempt was made to acquire similarly detailed data on the fathers of the Original Series. In addition, a chromosome study of the fathers was undertaken in order to determine whether there was any detectable residual damage in the chromosomes of the peripheral blood. The results of this segment of the study are not included in the report, but are described as "to be reported elsewhere in detail" (NB: Conversation with Dr. Cohen on 3/21/79 indicates that the report on chromosomal effects is still in preparation.) After considering the more detailed exposure information the following findings were reported in the Current Series: 15.7% of case fathers and 21.3% of control fathers had received radar exposure; combining the probably-exposed with the definitely-exposed groups, the corresponding values were 26.0% and 28.3%. The reevaluated Original Series values for definitely-exposed fathers were 18.6% for case fathers and 15.2% for controls, and when probably-exposed fathers were added the values were 20.6% and 15.7%.

In terms of military services, without regard to radar exposure, there was a slightly higher frequency of case fathers with previous military service than control fathers: 64.2% vs 61.3% for both series combined, 60.2% vs 56.5% for the Original Series and 71.1% vs 69.5% for the Current Series. ++

When the data from the Original Series and from the Current Series were combined, the values for case vs control fathers were 17.4% vs 17.5% for definitely exposed and 22.7% vs 20.6% when "some" exposure was included. None of the foregoing comparisons showed statistically significant differences. ++

The authors concluded that the Current Series did not confirm the suggestions of the Original Series that there was either an excess of radar exposure or a larger proportion among fathers with military service prior to the conception of the Down's case. The authors note that "in view of the suggestive findings of the original series with regard to a possible radar association, it was certainly necessary to investigate this question further. The initial steps were taken. A replication study was the simplest and least expensive immediate approach. Supplementing it with the independent search of service records added an objective approach eliminating any possible differential in parental responses. These methods having been attempted with inconclusive findings, it is now necessary to look to the prospective, longitudinal, surveillance studies to resolve the issue." ++

Robinette and Silverman (1977) examined the causes of mortality in World War II Navy personnel through 1977. About 40,000 decedents were assigned in approximately equal numbers to either RFR-exposed or control groups on the basis of Navy occupational + +

title (no quantitative exposure data were available). The exposed group consisted of repair men (electronics, fire control and aircraft electronics technicians) and the control group consisted of radio-frequency equipment operators (radiomen, radarmen and aircraft electrician's mates). The exposed group was considered as having more chance of being exposed to radar emissions than the control group. While an unexposed group would have strengthened the study, the two groups selected were presumably similar in terms of non-radar factors. Assigning cases to groups on the basis of occupational titles is a common procedure in RFR epidemiological studies (see below). They found a significantly higher death rate from trauma in the exposed group; however, many of the trauma-associated deaths resulted from military aircraft accidents and a higher proportion of the exposed group had subsequently become flyers. The incidence of deaths associated with arteriosclerotic heart disease was significantly lower in the exposed group. No significant differences were noted between the two groups in terms of total mortality or in terms of mortality from any of about 20 assigned categories of causes of death. The overall death rates for both groups were lower than those for the comparable age group in the U.S. population at large.

In a summary of the results of ophthalmologic examinations of 605 RFR workers and 493 individuals with no known exposure to RFR, Appleton (1973) presents data that indicate no significant differences between age-matched groups in terms of opacities, vacuoles, or posterior subcapsular iridescences in the lens of the eye. The level of microwave exposure was not quantified, but remained in qualitative terms, i.e., "could have been exposed" and "almost certainly had not been exposed." A more detailed discussion of this study is given in Section C.7.4.2, p. C-42.

In 1971, Peacock, et al. used birth records to compare the incidences of congenital anomalies in each of the 67 Alabama counties during the 17-month period from July 1969 to November 1970. Using the statewide average to compute the expected number of anomalies, they reported that anomaly incidences of specific categories departed significantly from a random distribution for white populations in six counties: Calhoun, Henry, Butler, Jefferson, Coffee and Dale (2 categories) Counties. For non-white populations, only Calhoun County had a significant departure from the expected incidence. No interpretation in terms of causal factors associated with the excess incidences was included in the report.

In November 1973, Peacock, Williams, and Nash submitted a report to the EPA from the Southern Research Institute based on both a reexamination of the birth-record data included in the 1971 report of Peacock et al., and examination of additional birth records so that a four-year period from 1968 to 1972 was covered.

This report focused on the anomaly and fetal death rates in Coffee and Dale Counties and at the Fort Rucker military hospital (Lyster General) and invoked a causal association between anomaly rates and fetal deaths and emissions from the 46 radar installations in and around Fort Rucker, which is located in Coffee and Dale Counties. Alabama statewide incidences and incidences at other "non-radar" military hospitals were used as controls. In addition, the fetal death rate for the hospital at Eglin AFB, another "radar" hospital, was also reported. The authors reported that, on the basis of the 4-year data and after making adjustments for "non-radar" factors, the Lyster Hospital anomaly rates in several categories were abnormally high for all anomalies, heart, genital organs and musculoskeletal categories, and that the evidence was strong that the rates were also abnormally high for fetal deaths, circulatory and respiratory systems, cleft palate, and in the skin-hair-nail categories. The Eglin AFB Hospital fetal death rate was nearly identical to that for Lyster Hospital. Upon reevaluation, the apparently high rate for clubfoot, initially a category that pointed most convincingly to a localized problem, was attributed to reporting differences.

The Coffee and Dale County data were not subjected to adjustments for "non-radar" factors. Compared with the statewide incidences and assuming random distribution and consistent reporting practices the authors reported statistically significant excesses for all anomalies and for fetal deaths in both counties and for heart anomalies in Dale County, and abnormally high incidences for four other categories in each of the two counties. The abnormally high rates of reported anomalies were described as primarily a phenomenon of the white population in the two counties. ++

In March 1976, Burdeshaw and Schaffer submitted a report from the Southern Research Institute to the EPA based on the same Alabama birth record anomaly data from 1968-1972. Instead of using statewide averages as a control for county incidences, Burdeshaw and Schaffer compared the Coffee and Dale County data with that for each of the other 65 Alabama counties on a score and rank basis. In addition they sent questionnaires to 46 Alabama hospitals in order to acquire more detailed information on hospital characteristics and reporting procedures and used the more detailed information to predict expected values for Lyster General Hospital. They considered the findings that the two highest hospital anomaly rates were from Fort Rucker and Maxwell AFB (both military aviation centers) and that 13 of 17 Alabama counties with anomaly rates in the upper quartile were in a contiguous band from southeast to westnorthwest Alabama as evidence that there was a geographically distributed anomaly problem. However, they also found evidence against the conclusion that there was an unusually high anomaly incidence rate specifically in the Fort Rucker area: Overall rates for Coffee and Dale Counties ranked only sixth and eighth among the 67 Alabama counties; at least five other Alabama hospitals reported ++

anomaly incidences that were not significantly lower than for Lyster Hospital; Lyster's overall rate was within predicted limits for hospitals with its characteristics; there was no clustering of residences of mothers with anomalous children in the vicinity of radar sites; carefully controlled surveys from other (non-Alabama) hospitals revealed anomaly incidences consistent with Lyster's; and significant time-clustering of anomalies at Lyster indicated a high reporting rate for one or two particular physicians. In conclusion, they stated that on the basis of the birth record data, it could not be concluded that an unusually large number of infants with congenital anomalies were born to military personnel at Fort Rucker or to other residents in the immediate area.

It is estimated that the U.S. Embassy in Moscow has been subjected to microwave irradiation since 1953. Prior to 1963 the presence of the microwave signal was noted during intermittent routine checks. Beginning in 1963, nearly continuous monitoring of the signal characteristics has been in process. A report on the evaluation of the health status of U.S. personnel who had been assigned to the Moscow embassy during the period 1953-1976 was published on July 31, 1978. It is entitled "Foreign Service Health Status Report," subtitled "Evaluation of Health Status of Foreign Service and Other Employees from Selected Eastern European Ports," and was prepared under the direction of Abraham Lilienfeld, M.D., of the Johns Hopkins University. ++

The report estimates that signal frequencies have ranged from 2.5 to 4.0 GHz. The maximum incident power densities were described according to time period: 1953 to May 1975, 5 microwatts/$cm^2$, 9 hours/day; June 1975 to February 7, 1976, 15 microwatts/$cm^2$, 18 hours/day; since February 7, 1976, fractions of a microwatt/$cm^2$, 18 hours/day. ++

After considerable effort spent in tracing employees and dependents, 1,827 employees and 1,228 dependents were identified as having been at the Moscow embassy during the 1953-1976 period. 2,561 employees and 2,072 dependents assigned to embassies and consulates in Budapest, Leningrad, Prague, Warsaw, Belgrade, Bucharest, Sofia and Zagreb during the same time period were identified as controls. Periodic tests for microwave radiation at the control sites showed only background levels. ++

Medical records were reviewed for 1,209 Moscow employees and 834 dependents. The corresponding numbers for the control group were 1,882 and 1,507. Health questionnaires were returned by 969 Moscow employees and 1,129 control employees. The number of completed dependent questionnaires is not clearly specified in the report. ++

The authors of this study recognized and commented on the limitations placed on the study by their inability to acquire complete sets of medical records, death certificates and returned ++

health questionnaires, and by the imprecision of the classification of the individual employees according to probable extent of radiation exposure. Further, they noted that the highest exposure levels were recorded late in the study and therefore, for the subgroup with the highest exposure, the period of time during which health effects might become apparent was the shortest. They also noted that the size of the study population was insufficient to detect excess risks that were less than two-fold for many of the medical conditions studied. However, despite these acknowledged limitations, the authors were able to draw the conclusions below.

There were no discernible differences between the Moscow and control groups in total mortality or mortality from specific causes, nor were there differences in mortality between the Moscow and control groups of dependent children or adults. With the exception of cancer-related deaths among female employee groups (both Moscow and control), mortality rates for both Moscow and control groups were less than for the U.S. population at large. While the study groups were subject to a large variety of health problems, on the basis of the medical records these problems were shared nearly equally by both Moscow and control groups with two exceptions: the Moscow male employees had a three-fold higher risk of acquiring protozoal infections and both men and women of the Moscow group were found to have slightly higher frequencies of most of the common kinds of health conditions reported. However, the authors could not relate these two exceptions to microwave radiation. From the health questionnaire information, the authors reported that there were some excesses in the Moscow employee groups as compared with the controls: More correctable refractive eye problems, more psoriasis in men and anemia in women, and more frequent cases of depression, irritability, difficulty in concentrating and memory loss. However, the authors noted that "In view of the possibilities which had been publicized of the increased danger to their health and that of their children, it is not at all surprising that the Moscow group might have had an increase in symptoms such as those reported. However, no relationship was found between the occurrence of these symptoms and exposure to microwaves; in fact, the four symptoms mentioned earlier, which showed the strongest differences between the Moscow and Comparison groups, were all found to have occurred most frequently in the group with the least exposure to microwaves." ++

For dependents, the authors found no differences between the adult Moscow and control groups. Moscow dependent children had twice as high a frequency of mumps as the control children. The incidence of congenital anomalies occurring in children born after arrival of the parents at the duty station were comparable between the Moscow and control groups. ++

Finally, the authors summarized as follows: "With very few exceptions, an exhaustive comparison of the health status of the ++

State and Non-State Department employees who had served in Moscow with those who had served in other Eastern European posts during the same period of time revealed no differences in health status as indicated by their mortality experience and a variety of morbidity measures. No convincing evidence was discovered that would directly implicate the exposure to microwave radiation experienced by the employees at the Moscow embassy in the causation of any adverse health effects as of the time of this analysis."

Siekierzynski (1974) compared the causes of unfitness for work and incidences of lens translucency and of several neurotic disturbances in 507 Polish male radar station workers occupationally exposed to more than 200 microwatts/cm$^2$ with those for a group of 334 men at the same radar stations exposed to less than this value for periods ranging from 2 to 16 years. No correlations between the degree of exposure or the duration of employment and any of the criteria of effect were found. The author states that no appropriate control (unexposed) group was available and that the two groups were highly matched except for exposure intensity.

Pazderova (1971), also cited in Section C.7.9, p. C-64, reported on the results of a battery of medical evaluations carried out on 58 employees of Czech television transmitter stations. Exposure fields were estimated to range from 48.5 to 230 MHz at field intensities equivalent to 0 to 22 microwatts/cm$^2$, with a mean exposure duration of 7.2 years (10.6 hr/workday). These exposure parameters appear similar to those predicted for PAVE PAWS. Electrocardiograms, heart and lung X-rays, erythrocyte sedimentation rates, urinalyses, and liver function tests were conducted, as well as hematologic, serologic, ophthalmologic, neurologic, gynecologic, psychiatric, and psychologic examinations. The only statistically significant finding was that the mean plasma protein levels were higher than "normal" values taken from the literature, a finding that even the author finds unexplainable. The appropriateness of the use of literature control values is highly questionable, and the author notes the desirability of a control group matched for "age, way of life and educational background."

Sadcikova (1974) summarized data for two groups of USSR RFR workers; 1,000 people who were subjected to up to a few thousand microwatts/cm$^2$ and 180 workers who were exposed to up to a few tens of microwatts/cm$^2$ were compared with a group matched for age and character of work but not exposed to RFR. (Note that, although the Soviet occupational standard for exposure to RFR is 10 microwatts/cm$^2$, Sadcikova was able to locate 1,000 people exposed to up to several hundred times this level.) Of 16 kinds of symptoms reported, the incidences were higher for the higher-power-density group in 5 cases, higher for the lower-power-density

group in 9 cases, and essentially equal in 2 cases. Values of symptoms for the control group were less than those for at least 1 of the 2 exposed groups in all 16 cases. Symptoms reported included fatigue, irritability, sleepiness, partial loss of memory, bradycardia, hypertension, hypotension, cardiac pain, and systolic murmur. A table in the report describes 100 cases of "microwave sickness," and the text predicts little chance for recovery unless the patient is removed from the work environment.

Kalyada, et al. (1974) related narrative clinical evidence indicating that a number of symptoms were observed in people occupationally exposed to "non-thermal intensities" of RFR at 40-200 MHz for periods ranging from 1 to 9 years. The symptoms were described as vegetative dysfunction of the central nervous system, thermoregulatory pathology, cardiovascular changes, elevation of plasma cholesterol, and gastritis and ulcers. The authors refer to statistically significant changes, but no actual statistical data are presented. The authors also refer to control subjects, but the incidences of these symptoms in exposed workers is not compared with that in the general population.

Klimkova-Deutschova (1974) surveyed various industrial worker populations including metal welders, steel factory workers, plastic welders, technicians operating radio or television transmitters, and people working in research institutes and other industries that involve exposure to RFR. Miscellaneous administrative staff members were studied for comparison. Frequencies varied according to the place of exposure, ranging from 1 to 150 MHz, 300 to 800 MHz, or from 3 to 30 GHz, and the power densities, where specified, ranged from 100-3,300 microwatts/cm$^2$. The observations involved 530 people, and the findings included electroencephalographic disorders, consisting of synchronized waves of high amplitude and slow rhythm, and biochemical changes, including elevation of fasting blood glucose, serum beta-lipoprotein, and cholesterol. Changes in brain-wave patterns and in blood sugar, protein and cholesterol levels were described as more pronounced in the people exposed in the 3-30 GHz range.

The U.S., Polish, and Czechoslovakian studies offer no evidence of detrimental effects associated with exposure of the general population to RFR. Consistent with the voluminous, earlier Soviet literature, the Soviet studies offer findings that occupational exposure to RFR at higher levels than expected for general public exposure to PAVE PAWS does result in various symptoms, particularly those associated with CNS disorders. Since the USSR symptomatology has never been reported in Western studies, and because there are marked differences in the procedures used in reporting data between the Soviet and Western publications, a prediction based on epidemiologic evidence as to whether PAVE PAWS emissions will present a hazard depends on an individual's willingness to accept Soviet findings at face value. It is concluded that, taken as a whole, these epidemiologic

reports do not constitute evidence that the PAVE PAWS emissions will constitute a hazard to the population.

### C.7.2 Mutagenic and Cytogenetic Effects

Mutagenic effects of RFR have been reported for almost 30 years (Brauer, 1949), and cytogenetic effects were first reported almost 20 years ago (Heller, 1959). Mutagenesis has been studied in plants, bacteria, fruit flies, and mammals. Cytogenetic studies (of abnormalities of chromosomes and mitotic figures) have been performed on a variety of cells, including cultured human lymphocytes and other mammalian cells. Mutagenic studies on bacteria with RFR have generally had negative results (Blackman, 1976).

A study of mutagenesis in the flowering plant Antirrhinum majus L. was performed at 20 MHz. The pollen was exposed to field strengths of 1.5 V/m for 4 to 44 hours and crossed to styles of plants not exposed; embryonic death in the following generation was observed (Harte, 1975). Exposure for 4 hours produced no mutations, but exposure for 12 hours increased the embryonic death rate to 2.5 times the control level and exposure for 43.75 hours increased the embryonic death rate to 3.25 times the control level. Although a direct mutagenic effect of the radiation cannot be ruled out, the effect appears to have a definite, rather high, dose (field strength times time) threshold, and for a considerable range of doses, mutagenesis does not increase with increasing dose. Neither of these patterns is normally produced by agents that are directly mutagenic. A possible explanation for the effect is suggested by a study of corn seeds exposed to RFR (Bigu-Del-Blanco, 1977). The irradiated corn seeds were found to have lost considerably more water than control seeds incubated at the same temperature, and this water loss resulted in arrested growth. Water loss from the pollen in the Antirrhinum experiment is a mechanism that could account for the observed kinetics of the effects.

Studies of mutagenesis by RFR have been carried out in the fruit fly, Drosophila melanogaster. Most of these studies appear to have been performed at higher (10-100 GHz) or lower (20-35 MHz) frequencies than the present region of interest (ca. 450 MHz). In a study of nondisjunction of X and Y chromosomes at mating (a conventional mutagenesis test), Mickey (1974) found no effect from 4 hours of exposure to pulsed RFR at 20-35 MHz. Another study with RFR at 17 and 73 GHz (Dardalhon, 1977) showed no mutagenic effect in Drosophila, even after 2 hours of exposure at 60,000-100,000 microwatts/cm$^2$.

Studies of RFR-induced dominant lethal mutation in mammals have also been carried out. Varma (1975a) exposed male Swiss mice to 1.7 GHz microwaves at 50,000 microwatts/cm$^2$ for 30 minutes, or to 10,000 microwatts/cm$^2$ for 80 minutes, and then bred the mice to unexposed females for 7 to 8 weeks after irradiation. Females were examined on the 13th day of gestation, and the number of implants and early embryonic deaths (dominant lethals) were scored. Another study (Varma, 1975b) used the same technique but different doses of radiation (2.45 GHz, 100,000 microwatts/cm$^2$ for 10 min; or 50,000 microwatts/cm$^2$ for 3 x 10 min. in 1 day or 4 x 10 min. in 2 weeks). From the first study, the authors concluded that dominant lethal mutations occurred after exposure at both power density levels. From the second study, they concluded that the single exposure at the higher power densities was mutagenic, but the multiple exposures at the lower power densities were not. Review of the actual data shows a considerable discrepancy in the spontaneous rate of occurrence of dominant lethal mutations in the two studies (1% in the first, 5% in the second), even though the same types of animals were used and the two studies were conducted by the same principal investigator at the same location; furthermore, in recalculation, errors were found in the computation of the chi-square used for evaluation of the results. If the two studies are considered separately, and the chi-square values are recalculated, the first study shows a marginal, but significantly increased number of dominant lethal mutations for both the 10,000 and 50,000 microwatts/cm$^2$ exposures, and the second study shows no increase for either the 10,000 or 50,000 microwatts/cm$^2$ exposure. If both studies are consolidated, no mutagenic effect can be shown. The irradiation was performed on anesthetized animals, and the description of the method does not indicate that the scoring of mutations was blind (performed by an observer with no knowledge of group identification).

A more recent study on dominant lethal mutations in rats (Berman, 1978a) used a variety of power densities (5,000-28,000 microwatts/cm$^2$) at frequencies of 425 MHz and 2.45 GHz and involved repeated daily exposures over periods as long as 3 months. The study found no evidence of impaired reproductive efficiency or mutagenesis. The abstract stated that reevaluation of data previously published by others on RFR-induced dominant lethals in rodents did not confirm the existence of mutagenic effects, but details of the analysis are not currently available.

A large number of cytogenetic studies with RFR have been conducted. Heller (1959) first reported the induction of chromosome aberrations in cells of garlic root-tips by exposure to 27 MHz RFR. A calculation from the sketchy description of exposure conditions indicates that the power density was somewhere between 2,500 and 600,000 microwatts/cm$^2$. Another study co-authored by Heller (Mickey, 1975) reported the induction of chromosome aberrations in lung cells, bone marrow cells, and spermatogonia of Chinese hamsters exposed <u>in vivo</u>. The same study reported induction of

similar effects by exposure of Chinese hamsters in vivo with pulsed K- and X-band RFR (approximately 18 and 10 GHz, respectively). The report is not well organized, making it difficult to determine the exact experimental conditions used in each section of the study; however, all of the studies involved long exposures, up to 35 hours, at relatively high power levels (200,000-500,000 microwatts/cm$^2$), with inadequate dosimetry.

In another study of cytogenetic effects (Chen, 1974), Chinese hamster cells and human amnion cells were exposed in vitro to 2.45 GHz RFR at power levels from 200,000 to 500,000 microwatts/cm$^2$ for periods ranging from 1.5 to 20 minutes. A variety of chromosomal aberrations was observed. The incidence of aberrations did not increase with increasing dose or duration of exposure, and the findings were not significantly different from those in controls, although the author described individual clusters of aberrations as varying "noticeably from control."

Another study of Chinese hamster ovary cells (Livingston, 1977) exposed in vitro to 2.45 GHz RFR showed that the exposure increased the level of sister chromatid exchange frequency above the control level, but that the same effects could be produced by heating the cultures in a water bath to the same temperature as that produced by the RFR.

A study of human lymphocyte cultures exposed to pulsed RFR (2.95 GHz) at 7,000 or 20,000 microwatts/cm$^2$ showed that chromosomal aberrations were produced after exposure at 20,000 microwatts/cm$^2$ for 10 minutes or longer (Stodolnik-Baranska, 1974b). The temperature of the culture medium rose slightly during the 20,000 microwatts/cm$^2$ exposure, but remained constant during the 7,000 microwatts/cm$^2$ exposure. No chromosomal aberrations were reported for the exposure to 7,000 microwatts/cm$^2$, though the exposure was continued for 3 to 4 hours.

In summary, mutations and chromosome aberrations have been produced following RFR exposure in a number of experimental test systems. All of the results have occurred under conditions of comparatively high power levels, prolonged duration of exposure, or both. The conditions of exposure and the kinetics of the rate of production of either mutations or chromosome aberrations are consistent with the assumption that the results are produced by incidental effects of the radiation, e.g., heat arising from absorption of the RF energy. No evidence of intrinsic mutagenic activity of RFR has been found. Somewhat conflicting results were found in separate studies in mammals, using the dominant lethal test. The difference may partly be explained by the fact that in one pair of studies showing positive results, the animals were anesthetized during exposure. Anesthesia in mice and rats suppresses the normal body temperature control mechanisms, rendering the animals much more susceptible to large increases in temperature in localized regions of the body. In the other study, using

power levels meeting current radiation exposure guidelines, no evidence of mutation was found, even though exposures were protracted.

### C.7.3 Studies on Teratogenesis and Developmental Abnormalities

Teratogenic effects have been studied in insects, birds, mice, and monkeys. The insect model has commonly been the darkling beetle, Tenebrio molitor. An early preliminary report (Rosenbaum, 1977a) indicated that exposure of beetle pupae for 8 hours at 500 microwatts in a waveguide at 9 GHz produced teratogenic effects. Details of the findings were not given, and changes in temperature were not reported. Another study from the same laboratory (Rosenbaum, 1977b) reported teratological effects at power levels greater than 20,000 microwatts (9 GHz, 2 hours exposure). Temperature increase in these experiments was stated to be less than 2 deg C. It was also stated that previously traumatized pupae were more susceptible to RFR-induced teratogenesis. A separate study (Pickard, 1977) found that both the spontaneous and the RFR-induced abnormalities of the beetles depended on the source of the larvae and the diet fed to them before they entered the pupal stage. Whether RFR-produced abnormalities occurred also depended on the orientation of the beetles with respect to the electric and magnetic vectors of the field. Under conditions that promoted the induction of abnormalities, a marginal teratogenic effect was produced at 5.96 GHz by a 2-hour exposure at a mean SAR of 54 mW/g (approximately equal to 192,000 microwatts). A report from a separate laboratory (d'Ambrosio, 1977) showed that exposure to 9.55 GHz at 10 milliwatts waveguide power (no estimate of power density at animal possible) for 2 hours increased developmental abnormalities; temperature changes and environmental control measures were not reported.

More recent evidence involving infrared thermography of pupae (Olsen, 1978) indicates that the distribution of temperature under RFR exposure is significantly nonuniform as a result of differential distribution of water content in the pupa, and that localized regions may have elevated temperatures adequate to explain the observed teratogenic effects. This nonuniform temperature distribution would not be obtained by elevating the temperature of the pupa by conventional means. ++

Exposure of chick embryos during the first 5 days of development at a mean power density of 3,300 microwatts/$cm^2$ (frequency and other experimental conditions not stated) resulted in changes in the cranial size of the embryos at day 5 of development (Fisher, 1977). The effect appeared to depend upon the temperature of the incubator, opposite effects being obtained at incubation temperatures of 33.5 deg C and 35.1 deg C. Other teratogenic effects have been reported in chick embryos exposed during development to 20,000 microwatts/$cm^2$ for 280 to 300 min.

(Wheater, 1977a). Studies of Japanese Quail embryos exposed to continuous RFR exposure (2.45 GHz, 5,000 microwatts/cm$^2$) during the first 12 days of development (McRae, 1977) found no gross deformities at hatching. A slight increase in blood hemoglobin and a slight decrease in blood monocyte count was observed in the exposed birds. A further study (Hamrick, 1977) showed that exposed male birds were slightly smaller than control birds at 4 and 5 weeks of age. Exposed birds had the same level of immunocompetence as control birds.

Several independent studies have been conducted on the teratogenic effects of RFR on mice and rats. Dietzel (1975) exposed rats to 27.12 MHz RFR on various days of pregnancy. Doses were monitored by measuring rise in rectal temperature. Fetal malformations differed according to the day of gestation that was chosen for exposure; the malformations were not different from those produced by other teratogenic agents. No malformations were produced unless the radiation dose was high enough to raise rectal temperature by 2 deg C. Rugh (1975) exposed mice to RFR (2.45 GHz) at doses of 3 to 8 cal/g (123,000 microwatts/cm$^2$ for 2 to 5 minutes) on the eighth day of pregnancy and found a number of abnormalities in the fetuses, including resorptions and exencephaly. The incidence of abnormalities was dose-dependent; no abnormalities were reported below 3 cal/g (2 minutes exposure), and the incidence of abnormalities in controls was not stated. Chernovetz et al. (1975) exposed mice to RFR (2.45 GHz) at a dose of 22.8 J/g (135,000 microwatts/cm$^2$ for 10 minutes) on the 11th through 14th days of pregnancy, and they observed a marginal increase in fetal abnormalities. Of 131 fetuses in the exposed group, 10 were abnormal; 7 of 138 in the control group were abnormal. The difference is not significant (Fischer exact test). Berman et al. (1978b) exposed mice to RFR (2.45 GHz) at 3,400-28,000 microwatts/cm$^2$ for 100 min/day during gestation, and found 27 anomalies among 3,362 live fetuses exposed to RFR, as opposed to 12 among 3,528 sham-irradiated controls. Because of the small number of results for each individual anomaly and irregularities in the dose response and distribution of findings among the groups, the authors were in general unable to conclude that the anomalies resulted from the RFR exposure. The study was very well designed and executed, and illustrates and discusses very well the difficulties encountered in quantifying events that may be expected to occur only rarely in a population. The bibliography of this study is more extensive than what could be covered in the present document, and the reader may consult it for further references. ++

Several studies have been conducted in rats and monkeys (Reiter, 1976; Rosenstein, 1976; Kaplan, 1978 -- also discussed in C.7.5.5, p. C-53, and C.7.11.3, p. C-70) to determine the effects of RFR exposure (425 MHz, 2,450 MHz; 100-10,000 microwatts/cm$^2$) of pregnant animals in the neurological and behavioral development of their offspring. All tests for behavioral and neurological effects have shown negative results (no effects).

In summary, a number of teratogenic effects are produced by RFR at various frequencies. In mammals the effects appear to be associated with the production of heat in the gravid animal and an increase in body temperature. In bird eggs and insect pupae, the effects are also generally associated with temperature increases.

Teratogenic effects are generally caused by disturbances in the rate of growth and development of the embryological structures, rather than by direct cytotoxic effects of the teratogenic agent. Hence, in poikilothermic systems (bird eggs, insect pupae), relatively small temperature differentials can cause unbalanced growth that could lead to structural abnormalities. In mammals, there is the additional complication that handling the animals may cause stress, which may contribute to the teratogenic effect.

The studies on RFR-induced teratogenesis support the conclusion that the effects are due to heat production and do not reflect any special teratogenic properties of RFR. At the power densities existing at or beyond the 1,000-ft exclusion fence of PAVE PAWS there is no evidence of potential hazard to pregnant women or to the children that they carry.

### C.7.4 Ocular Effects

#### C.7.4.1 Animals

Many studies on animals of ocular effects due to RFR exposure, conducted over the past 30 years, strongly indicate that eye damage results only if intraocular temperatures increase by 5 deg C (9 deg F) or more (Guy, 1974; Williams, 1955; Daily, 1952, Richardson, 1948). This conclusion is supported by investigations in which lens opacifications produced by RFR exposure alone did not occur when the eye was cooled during exposure (Kramar, 1975; Baillie, 1969a, 1969b).

The inverse relationship between average power density and exposure duration for cataractogenesis is evident from the variety of exposure conditions used in these investigations. The evidence indicates the existence of a threshold power-density/exposure-time value of about 150,000 microwatts/cm$^2$ for single or multiple exposures of tens of minutes or more (Carpenter, 1977; Ferri, 1977, Guy, 1974; Appleton, 1973; Stodolnik-Baranska, 1974a; Birenbaum, 1969; Williams, 1955). For example (Guy, 1974), at power densities ranging downward from 500,000 microwatts/cm$^2$ to about 200,000 microwatts/cm$^2$ at 2.45 GHz, the exposure duration necessary to produce cataracts in the rabbit increased from 1-2 minutes to about 20 minutes. Also (Kramar, 1975), several series of *in vivo* intraocular temperature measurements taken at 200,000 microwatts/cm$^2$ during a 40-minute exposure period (using a thermocouple probe inserted immediately after each successive 5-minute exposure period with the RFR off) indicated that the vitreous

temperature rose from the normal body temperature of about 37 deg C (98.6 deg F) to about 42 deg C (107.6 deg F) during the first 10 minutes of exposure and remained at the latter temperature for the remaining 30 minutes of exposure. Presumably the plateau temperature represents equilibrium between the rate of energy absorption and the various heat removal mechanisms in that portion of the eye. After termination of exposure, the vitreous temperature rapidly returned to normal. By contrast, the temperature of the orbit, which is cooled to a greater extent by blood flow than the vitreous, rose to a plateau of less than 40 deg C (104 deg F). Most significant in these investigations, however, was evidence of the previously mentioned cataractogenesis threshold power density of about 150,000 microwatts/cm$^2$; i.e., curves of power density versus exposure duration show that the power density for cataractogenesis approaches this value asymptotically. Also, exposure at 100,000 microwatts/cm$^2$ for durations of up to at least 100 minutes failed to produce any cataracts. (Exposures of longer duration were not used in this investigation.) The experimental results of others (Carpenter, 1977; Birenbaum, 1969; Williams, 1955) also indicated the existence of a cataractogenesis threshold of comparable magnitude.

Much of the ocular work cited here was performed at frequencies above 1 GHz (typically at 2.45 GHz, but ranging up to 24 GHz). However, there is some experimental evidence that the cataractogenesis threshold value at 918 MHz is higher than at 2.45 GHz (Guy, 1974), which suggests that it would be still higher at 450 MHz. Also, in earlier experimental work (Cogan, 1958), no eye damage was observed in rabbits exposed at 385 or 468 MHz to power densities of about 60,000 microwatts/cm$^2$.

Several researchers (Ferri, 1977; Williams, 1974; Reider, 1971; Richardson, 1951) compared the ocular effects of pulsed and CW RFR at equivalent average power densities greater than 100,000 microwatts/cm$^2$. Exposure periods were typically about 1 hour/day for several weeks. No significant differences between the effects of pulsed and CW RFR could be detected.

The results summarized above have been regarded as strong evidence that single or multiple exposures over indefinitely long periods of time at power densities well below the threshold (e.g., at 10,000 microwatts/cm$^2$ or lower) would not cause eye damage to humans or any other species. Consequently, very little experimental research has been done on possible cataractogenesis in animals, using chronic exposures at low-levels. One investigation currently under way (Chou, 1978) has several biological endpoints. In this study so far, one group of six rabbits was exposed to 2.45 GHz CW at 1,500 microwatts/cm$^2$ for 2 hours per day over a period of 3 months; another group was similarly exposed to pulsed RFR at the same frequency and average power density at a duty cycle of 0.001 (10-microsecond pulses of 1,500,000 microwatts/cm$^2$ pulse power density at 100 pulses/s), and a third group was sham-exposed.

No statistically significant differences among the three groups were observed in periodic eye examinations for cataract formation or in measurements of body weights, EEG and evoked potentials, hematology, or blood serum chemistry.

The findings above on animals indicate that RFR cataractogenesis is essentially a gross thermal effect.

C.7.4.2 Humans

Retrospective epidemiological studies of RFR-induced cataractogenesis have been carried out by Zaret (1961) and Appleton (1973), among others. Appleton, for example, conducted retrospective epidemiological studies of military personnel at several bases over a period of 5 years. In these studies, military personnel identified as having been occupationally exposed to RFR (from radars and communications systems) were matched in age and sex with controls, other military personnel at the same bases who were not occupationally exposed. Exposed and control personnel were examined by ophthalmologists for opacities, vacuoles, and posterior subcapsular iridescence, taken as diagnostic precursors of cataracts. The procedure used in these examinations ensured that the ophthalmologists did not know whether the person examined belonged to the exposed group or the control group. The data were analyzed statistically by age group, numbers of persons per age group, and the presence or absence of these three diagnostic criteria. More people in older age groups exhibited these signs, but analysis of the pooled data from several Army installations showed no statistically significant differences between exposed and control groups.

The principal investigator emphasized that the presence of any of the three diagnostic criteria did not necessarily mean that significant vision impairment had occurred. He also indicated that the use of the presence or absence of these signs as binary numerical data for the statistical analysis was necessary because of the complexity of the eye, and he recognized the unavoidable judgmental aspects in the diagnoses of each examining ophthalmologist. For example, the results of two of the ophthalmologists involved in the study of personnel at Tyndall AFB indicated the presence of opacities in 96% of the personnel in the exposed group and 93% in the control group. However, these ophthalmologists also concluded that "no optically significant opacities were found in either group."

It is difficult to ascertain the extent of the exposure histories (intensities, durations, etc.) prior to such a study. Also, the presence or absence of the three diagnostic criteria is only a crude measure of eye damage for use in statistical analyses. Despite these limitations of the study, its finding that there are no statistically significant differences between exposed and control groups is probably valid.

The results of these retrospective analyses of military personnel support the conclusion above that RFR cataractogenesis is a gross thermal effect. Therefore, it is extremely unlikely that prolonged exposure to the RFR from PAVE PAWS, certainly at the power densities outside the exclusion fence, will cause eye damage in humans.

## C.7.5 Nervous System Studies ++

This section includes studies on the RFR-hearing effect and field effects on calcium efflux from brain tissue (both also discussed in Section C.6.1.2, pp. C-22, C-23), studies of blood-brain barrier permeability, histopathology of the CNS, and studies of the EEG and evoked potentials.

### C.7.5.1 RFR-Hearing Effect

Using 2,450 MHz radiation, Foster and Finch (1974) repeated and extended White's (1963) findings that acoustic transients can be thermally generated in water by pulsed RFR energy. The peak pressure level of these transients, measured within the audible frequency band as a function of the RFR pulse parameters, is adequate to explain the "clicks" heard by people exposed to pulsed RFR of high pulse power density. They concluded that these thermally induced transients elicit the RFR "hearing effect" in humans.

Cain and Rissman (1976) investigated RFR hearing threshold parameters (3.0 GHz) for cats, dogs, chinchillas, and humans. Threshold auditory-evoked responses in the animals were obtained at an average density per pulse of 10.3 microjoules/$cm^2$ at pulse widths less than 20 microseconds. For similar pulse widths in humans, the average energy density for threshold of hearing the pulse was 10.6 microjoules/$cm^2$. However, three of the eight subjects could not hear pulses below 20 microseconds at maximum pulse power settings. The authors believe that an inability to hear RFR pulses might be correlated with hearing losses above a frequency of 8 kHz. The values for threshold detection of the acoustic effect corresponds approximately to 300,000 microwatts/$cm^2$, pulse power density, for a 20-microsecond pulse, which is more than two orders of magnitude above the calculated PAVE PAWS pulse power densities at the exclusion fence. +

Chou and Guy (1977) used 918 MHz radiation and guinea pigs to investigate thresholds for brainstem-evoked responses. They found that, for pulse widths less than 30 microseconds, the threshold was independent of the absorbed energy per pulse, which agrees with Cain and Rissman. For pulse widths greater than 70 microseconds, the threshold was independent of the pulse power density. Chou and Guy indicated that their experimental results agreed well with the predictions of the thermal expansion theory.

Chou and Galambos (1977) extended the above findings to investigate effects of external-ear blocking, middle-ear damping, and middle-ear destruction on the brainstem-evoked responses to both acoustic and RFR stimuli. They found that only when the cochlea was intact was the animal capable of hearing pulsed RFR.

In two papers, Lebovitz and Seaman (1977a, 1977b) reported on single unit responses (eighth-nerve related) to 915 MHz CW and pulsed RFR. The threshold for CW activation of vestibular units was significantly above 10,000 microwatts/cm$^2$ (i.e., above a level for significant intracranial thermogenesis). For cochlear units, use of pulse widths of 100-250 microseconds or longer confirmed that pulse parameters were a more appropriate independent variable than average power density. Single unit responses were observed at pulse energy densities of 4 microjoules/g and lower (comparable with results in previously discussed papers). The response of a given single auditory unit to pulsed RFR was very similar to its response to traditional acoustic click stimuli, differing only in amplitude.

Lin (1977a, 1977b) has reported on detailed theoretical studies of the RFR auditory effect. He assumed that the auditory sensation results from acoustic waves generated in the tissues of the head by rapid thermal expansion of the tissues upon microwave absorption (which is the general consensus of the foregoing reviewed papers). The theoretical results indicate the frequency of the auditory signals generated is independent of both the frequency of the incident RFR and the absorbed energy distribution. This indicates that this phenomenon, studied at frequencies such as 915, 2,450, and 3,000 MHz, would occur in the 420-450 MHz band if the peak power density and pulse duration were above the minimum values stated previously. Frequency of the auditory signal is dependent on head size. The smaller the head size, the higher the frequency of the RFR-induced auditory sensation. For a human infant, predicted fundamental frequency is 18 kHz. For an adult human, predicted fundamental frequency is 13 kHz.

Tyazhelov (1977b) reported on some peculiarities that Soviet researchers had noted concerning the RFR auditory sensation in human observers at 800 MHz. Confirming some of the work reviewed above, they noted that for pulse widths of 5 to 30 microseconds the threshold of pulse power density was essentially flat from 1 pps to approximately 1,000 pps. The threshold then rose and reached cutoff between 8,000 and 10,000 pps (maximum pulse power density 2,000,000 microwatts/cm$^2$). The average power density in these experiments on occasion must have been of the order of 100,000 microwatts/cm$^2$ or more for the Soviet subjects. Other observations included the successful generation of beat-frequency responses with an acoustic stimulus greater than 8 kHz, and an increase in threshold level as pulse widths increased toward 100 to 120 microseconds, with concomitant decrease in pitch. The authors concluded that current models of RFR hearing would require

further development. Further refinements of theory and experiment appear to be in progress.

Thus, in this one area, pulsed RFR effects are different from those of CW RFR at the same average power densities. The RFR hearing effect appears to be well understood in terms of thermoelastic expansion of tissues resulting from absorption of a pulse of microwave energy, with subsequent conduction of the acoustic pulse to the cochlear apparatus. Threshold for detection of a pulse by persons with normal hearing is of the order of 300,000 microwatts/cm$^2$, well above any levels predicted for the ground level vicinity of PAVE PAWS. +

### C.7.5.2 <u>Calcium Efflux</u>

Over the last 4 years, Adey and Bawin have reported extensively on their studies of changes of radioactive calcium ion ($^{45}Ca^{++}$) efflux from neonate chick brain preparations and isolated samples of cat cortex under very specific regimes of amplitude modulation frequencies and power densities for ELF, VHF, and UHF fields (Adey, 1975a, 1975b, 1976, 1977a, 1977b, 1978a, 1978b; Bawin, 1974, 1975, 1976a, 1976b, 1977a, 1977b, 1977c, 1978a, 1978b).

Certain of these reports are relevant to PAVE PAWS because they describe effects at 450 MHz, at relatively low power densities (100 to 1,000 microwatts/cm$^2$). The pulse rates of PAVE PAWS are also approximately the same as the modulation frequencies of Bawin and Adey. For these reasons, these studies are given +
emphasis in this EIS. +

Extensive details of the experimental protocol are given in Bawin (1976b, 1977a). Briefly, following decapitation, forebrain hemispheres of neonate chicks were obtained by rapid dissection. The hemispheres were separated and one was used for exposure and the other as control. Each was incubated in a specified physiological solution containing $^{45}Ca^{++}$ for 30 minutes. At +
the end of incubation, the samples were rinsed three times with nonradioactive solution. The samples were then transferred to new glass test tubes, bathed in 1.0 ml of solution and exposed or sham-exposed for 20 minutes. Sets of ten brain samples (ten exposed hemispheres, ten control hemispheres) were used simultaneously. At the conclusion of exposure, aliquots of 0.2 ml of the bathing solution were taken, and radioactivity assayed by scintillation counting. Radioactivities (counts per minute, cpm, +
per gram) were normalized to the mean value of counts obtained in control effluxes. All normalized data were compared (by t-test) with matched samples of control values. Data from experiments with approximately 190 chick brains for 450 MHz exposures are given in Adey (1977a). Power densities of 500, 1,000, 2,000, and 5,000 microwatts/cm$^2$ were used, for 16 Hz amplitude modulation

of the field. At 1,000 microwatts/cm$^2$, a significant (p less than 0.001) difference (9.3%) was observed between the normalized means of radioactivity counts of control and exposed brains. Exposed brains had the higher mean. A significant (p less than 0.01) difference was also observed for 500 microwatts/cm$^2$ (exposed mean 21% greater than control). Differences for 2,000 microwatts/cm$^2$ (exposed 1% greater) and 5,000 microwatts/cm$^2$ (exposed 3.5% less) were not statistically significant. The same data were reported by Bawin (1977a), with the caution that the experiment must be repeated to be compared with the other extensively studied field conditions (ELF, and 147 MHz).

A different set of data for 450 MHz has subsequently been reported by Bawin (1978a) and repeated by Adey (1978b). At 1,000 microwatts/cm$^2$, a significant (p less than 0.05) increase (10.9%) was observed between exposed and controls. A significant (p less than 0.05) increase (7.9%) was observed at 100 microwatts/cm$^2$. Increases of 3.4% and 2.1% at 2,000 and 5,000 microwatts/cm$^2$ were not statistically significant, nor was a 6.1% decrease at 50 microwatts/cm$^2$. ++

From the two sets of data therefore, statistically significant increases were seen at 100, 500, and 1,000 microwatts/cm$^2$, but not at 50, 2,000 or 5,000 microwatts/cm$^2$, for 450 MHz RFR amplitude-modulated at 16 Hz. A recent paper (Bawin, 1978b) describes experiments aimed at a better definition of the calcium sites responding to weak electrical stimulation. Changes in efflux were studied with and without imposed electromagnetic fields (450 MHz, 16 Hz amplitude modulation, 375 or 2,000 microwatts/cm$^2$) to ascertain the effect of calcium concentration in the exchanging medium. Also tested were pH and bicarbonate-free solutions. The second half of the study examined modification of calcium release by the addition of lanthanum to the bathing solution, for both no-field and with-field stimulation conditions. Efflux of $^{45}Ca^{++}$ in the standard physiological solution was the "control" for these experiments, and each half brain was tested against the corresponding hemisphere in any test series. ++

The results confirmed the previous findings by Bawin and Adey that amplitude-modulated 450 MHz fields can stimulate the release of preincubated $^{45}Ca^{++}$ from isolated brain tissue. This release was significantly different, statistically, at extracellular $Ca^{++}$ concentrations of 2.16 and 4.16 mM, but not in $Ca^{++}$-free solutions. The release was enhanced by addition of $H^+$ (0.108 mM, as HCl), even through this did not affect the efflux in the absence of the field. Omission of $HCO_3^-$ resulted in a decrease (not statistically significant) in efflux of $^{45}Ca^{++}$ both with and without field stimulation. Addition ++

of $La^{+++}$ to the $HCO_3^-$-free solution resulted in a statistically-significant decrease in $^{45}Ca^{++}$ efflux (compared with an increase in the other cases, above) for an extracellular concentration of 2.0 mM $La^{+++}$ for both no-field and with-field (375 and 2,000 microwatts/cm$^2$) situations. These results taken together are stated to support the hypothesis that a limited number of extracellular cationic binding sites are involved in the transaction of weak extracellular electrical events and suggest that the electrosensitive sites in $La^{+++}$-treated samples are in the class of sites responsible for the field response in the "standard" solution.

Bawin (1977c) has also reported on results from a preliminary study involving the monitoring of calcium efflux from the intact cortex of 12 awake, paralyzed cats. The methods were similar to those utilized in the chick brain experiments. The cats were exposed for 20 minutes to 450 MHz fields amplitude modulated at 16 Hz. Power densities were 375 or 1,000 microwatts/cm$^2$. Results are stated to be a clear increase in $^{45}Ca^{++}$ efflux during and following the exposure in 8 of 12 animals. However, some animals apparently responded to the presence of the experimenter during sampling. Further experiments are now in progress to remove the possibility of artifact and to elaborate on these preliminary findings.

Blackman (1977) reported on an attempt to verify and extend Bawin and Adey's findings for chick brain at 147 MHz. Treated tissue was exposed in a Crawford chamber to power densities between 500 and 2,000 microwatts/cm$^2$ and amplitude modulation of the carrier at selected frequencies between 3 and 30 Hz. They found a statistically significant increase in calcium efflux (p less than 0.05) when the frequency of modulation was 16 Hz and power density was 750 microwatts/cm$^2$. Their presentation constitutes the first reported independent confirmation at one power density and modulation frequency of Bawin and Adey's work at 147 MHz. Blackman experienced considerable difficulties initially in the work, but now has been able to repeat this finding on several occasions.

The work of Adey and Bawin represents one of the very few cases where RFR effects have been found at average power densities in a possibly non-thermal range (100-1,000 microwatts/cm$^2$). Schwan (1977, p. 207) has expressed the opinion that if the findings of Adey and Bawin can be confirmed and if it can be shown that they are caused by direct interaction with the CNS, entirely new modes of interaction of electrical fields with biological systems are indicated. It is also important to note again that the RFR carrier frequency used by Adey and Bawin (450 MHz) is very close to that of PAVE PAWS (420-450 MHz) and that the modulation frequency (16 Hz) is very close to the pulse repetition rates of PAVE PAWS (see Appendix D). However, there is no evidence at present that the findings of Adey and Bawin imply any hazard to

humans. Average and pulse power density levels of PAVE PAWS RFR to which the general public may be exposed will be lower than the threshold average power density found by Adey and Baswin. ++

### C.7.5.3 Blood-Brain Barrier Effects

Non-RFR studies by Rodzilsky and Olszewsky (1957) revealed that permeability changes in cerebral blood vessels occurred under various conditions, including those that produced heat necrosis. Sutton (1973) used 2,450-MHz radiation to produce selective hyperthermia of the brain in rats. He then studied the integrity of the blood-brain barrier with horseradish peroxidase (HRP), a protein tracer that can be detected both morphologically and quantitatively. Brains were heated to 40, 42, and 45 deg C. Barrier integrity was disrupted after heating for more than 45 min at 40 deg C. Animals with brains heated to 45 deg C survived for only 8 to 15 min. The most common site of vascular leakage was the white matter adjacent to the granular cell layer of the cerebellum. Sutton concluded that to prevent blood-brain barrier disruption, brain temperatures must not exceed 40 deg C in the absence of body-core hypothermia.

Frey (1975) exposed groups of anesthetized rats to pulsed or CW RFR at 1.2 GHz for 30 minutes. The pulse and average power densities of the pulsed RFR were 2,100 and 200 microwatts/cm$^2$, respectively, and the average power density of the CW RFR was 2,400 microwatts/cm$^2$. Sham-exposed rats were used as controls. After exposure, sodium fluorescein was injected into the femural vein. Five minutes after injection, the blood of the rat was withdrawn and the brain was removed, embedded in gelatin, refrigerated, and sectioned. The sections were viewed under ultraviolet light for fluorescence, the intensity of which was scored by the viewer. Greater fluorescence was reported for pulsed than CW RFR, and some control specimens also exhibited slight fluorescence. The investigators regard these results as evidence that exposure to RFR alters the blood-brain barrier. However, Spackman (1978) performed a similar investigation in mice, using fluorescein and several nonphysiological amino acids as test substances. Groups of mice were exposed to sham, CW, or pulsed RFR at 918 MHz for 30 minutes. The average power densities in both the pulsed and CW modes were 2,500 and 33,000 microwatts/cm$^2$. The duty cycle of the pulsed RFR was 0.001. Exposure to 132,000 microwatts/cm$^2$ CW was also tested. A spectrofluorometer and an automatic amino acid analyzer were used to measure concentrations of fluorescein and the test amino acids, respectively, in the brain and blood plasma. Using these more sensitive methods, the investigators did not detect any significant differences in blood-brain-barrier permeability between RFR-exposed and control mice. ++

Albert (1977a) also used HRP as a tracer and reported regions of leakage in the microvasculature of the brains of Chinese hamsters exposed to 2,450-MHz radiation at 10,000 microwatts/cm$^2$ for 2-8 hr. In control animals, extravascular reaction product was found only in brain regions normally lacking a blood-brain barrier. In a later paper, Albert (1977b) reported that continuation of the earlier studies indicated that a partial restoration of the blood-brain barrier's impermeability may have occurred within 1 hr after exposure ceased, and that restoration was virtually complete within 2 hr. Albert believes that these changes may be clinically subacute and probably cause no lasting ill effects. Further discussion of the possible thermal nature of these effects is given in Section C.7.5.4, p. C-51, in the discussion of Albert and De Santis (1975). Note that these leakages of the microvasculature of the brain occur irregularly. During the formal discussion period following presentation of a paper by Preston at the 1978 International Symposium on Biological Effects of Electromagnetic Fields in Ottawa, 27 June 1978, Albert indicated that such leakage is observed in approximately 50% of his exposed animals, and also in approximately 20% of his control animals. +

Changes in permeability of the blood-brain barrier to D-mannitol were investigated by Oscar and Hawkins (1977), who exposed rats to 1.3-GHz pulsed or CW RFR for 20 min at various power densities. Permeability changes were measured by the Oldendorf technique; that is, 0.2 ml of a mixture of $^{14}$C-labeled mannitol and tritiated water was injected rapidly into each rat's carotid artery after exposure, the animal was sacrificed 15 s later, and brain sections were dissected out and prepared for assays of radioactivity using a liquid scintillation counter. The ratio of counts of $^{14}$C-labeled D-mannitol to counts of freely diffusible tritiated water in samples of brain tissue was normalized to a similar ratio for the injected solution. This normalized ratio, expressed as a percentage, is defined as the brain uptake index (BUI). Oscar and Hawkins found statistically significant changes in BUI at average power densities less than 3,000 microwatts/cm$^2$. They also found that pulsed energy is not always more effective in causing permeability changes than CW energy. Instead, depending on certain pulse characteristics, pulsed energy can be either more or less effective than CW energy of the same average power density. They found that under conditions of high pulse power density, large pulse widths, and a few pulses per second, mannitol uptake could be affected at an average power density of only 30 microwatts/cm$^2$.

These results appear to be relevant to possible effects of PAVE PAWS RFR. However, attempts by Merritt (1977) to repeat the experiment did not confirm the original finding of increased permeability. Data from three separate experiments by Merritt indicated that hyperthermia of the brain was necessary to alter permeation. + + +

Preston (1978) also attempted to determine whether 2,450-MHz CW exposure increased blood-brain barrier permeability to $^{14}C$-mannitol. Rats were exposed to 100, 500, 1,000, or 10,000 microwatts/cm$^2$, and controls were sham exposed. Most methods were identical with those used by Oscar and Hawkins (1977). No evidence that the RFR exposure increased blood-brain barrier permeability to mannitol was found.

Chang (1978) used a technique involving radiolabeled $^{131}I$ albumin to investigate alterations of the blood-brain barrier in dogs. The dogs' heads were exposed to various power densities between 2,000 and 200,000 microwatts/cm$^2$. In general, no statistically significant differences were observed between exposed and sham-exposed animals, but the number of animals reported in this study was too small for a high level of statistical confidence.

In summary, it appears that blood-brain barrier permeability to HRP can be altered by levels of RFR sufficiently high to cause substantial temperature elevation. It is also possible that lower average power densities, in the vicinity of 10,000 microwatts/cm$^2$, may cause randomly distributed, clinically subacute, reversible alterations, although such alterations also occur (though less frequently) in unexposed controls. These effects are highly unlikely to occur at the radiation levels expected outside the PAVE PAWS exclusion fence. Radiotracer techniques have shown changes in permeability of the blood-brain barrier to D-mannitol at power densities less than 3,000 microwatts/cm$^2$, but other investigations have failed so far to confirm these findings. Oscar (1977) has pointed out that most techniques used to measure blood-brain barrier permeability in fact measure the net influence of several variables on brain uptake, and do not differentiate among the effects of changes in the vascular space, alterations of blood flow, and membrane permeability. Several research projects to refine knowledge of blood-brain barrier permeability change under RFR are apparently now underway.

### C.7.5.4 <u>Histopathology of the Central Nervous System</u>

Tolgskaya and Gordon (1973) reported a number of effects of RFR (frequencies 500 kHz to 100 GHz) on a large number (approximately 646) of animals, predominantly rats. Their so-called decimeter band (500 MHz - 1 GHz, exact frequency or frequencies not specified) is closest to the PAVE PAWS frequencies. Pathological effects claimed for high-intensity (20,000 to 240,000 microwatts/cm$^2$) radiation included multiple perivascular hemorrhages in the brain and other organs, degeneration of apical dendrites in the cortex, cloudy swelling of cytoplasm, cytoplasmic shrinkage, formation of vacuoles, unevenness of staining, disappearance of cytoplasmic structures, fatty degeneration, decrease in ribonucleoprotein, and occasional karyocytolysis. The intensities of expo-

sure were capable of causing death of the animals (clinical signs of hyperthermia, temperature rises up to 42 deg to 45 deg C) in several minutes to several hours. Photographs of the exposure arrangement show multiple animal exposures at the same time in a room appearing not to have radiation absorbing material on the walls. It is likely that the specific absorption rates (SARs) for individual animals under these conditions varied widely. Because all of these effects are clearly thermal in nature, they provide no evidence that the PAVE PAWS levels might prove harmful.

Low-intensity exposures were also carried out. The authors define threshold field intensities for nonthermal effects ("intensity not raising body temperature") for decimeter microwaves as 40,000 microwatts/cm$^2$ (Tolgskaya and Gordon, 1973, Table 3, p. 56). Exposures at so-called low intensity for decimeter waves were generally at or slightly below 10,000 microwatts/cm$^2$ for 60 minutes daily for 10 months. Investigation of the animals by ordinary morphological methods revealed practically no vascular disorders in the nervous system. "Delicate elective neurohistological methods" (unspecified) showed disappearance of spines from cortical dendrites, the appearance of beading and irregular thickening of dendrites, swelling of cytoplasm of individual cells (with appearance of vacuoles) in the basal ganglia and hypothalamus, focal and diffuse proliferation of microglial cells, with microglial processes showing initial signs of degeneration.

Many of these effects are similar to those described for the high-intensity exposures. In view of the approximately 10,000 microwatts/cm$^2$ exposure levels, the previously described exposure arrangement, and the knowledge of the possibility of localized regions of high SAR, it seems likely that the described effects (more subtle than those of frank hyperthermia) were also thermal in origin.

Albert and De Santis (1975) have also reported changes in the hypothalamus and subthalamus of Chinese hamsters exposed to 2,450 MHz radiation at either 50,000 microwatts/cm$^2$ for durations from 30 minutes to 24 hours, or 25,000 microwatts/cm$^2$ for 14 hours/day for 22 days. Changes were not evident in the hippocampus, cerebellum, thalamus, or spinal cord ventral horn. In the discussion printed with this paper, Guy pointed out that his laboratory had measured mean SARs as high as 4 W/kg per incident 1,000 microwatts/cm$^2$ in animals of similar size. Peak SARs could have reached 40 to 200 W/kg in selected brain regions of Albert's animals; this range far exceeds what is normally used for diathermy treatment in 20-minute exposures of patients. Rectal temperature measurement would not necessarily reflect such high SARs in localized areas. +

Albert and DeSantis (1976) studied CNS histological effects in 60 Chinese hamsters exposed to 1,700 MHz radiation at power densities of 10,000 and 25,000 microwatts/cm$^2$. Cytopathology was observed after 30 to 120 minutes of exposure in hypothalamic and

subthalamic areas, but not in other areas. These observed effects were also likely thermal in origin for the same reasons as above.

In summary, RFR can cause observable histopathological changes in the CNS of animals, but it appears that these changes are of a thermal nature and would not occur at the power densities existing outside the exclusion area.

### C.7.5.5 <u>EEG Studies</u>

Many studies on the electroencephalogram (EEG) and/or evoked responses (ERs) of animals exposed to RFR have been conducted. Some of these have been carried out with metal electrodes either implanted in the brain or attached to the scalp during exposure. Johnson and Guy (1972) pointed out that such metallic electrodes grossly perturb the fields and produce greatly enhanced absorption of energy (i.e., field enhancement) in the vicinity of the electrodes. Such enhancement produces major artifacts in the biological preparation under investigation. Such artifacts are not to be confused with the recording artifact that is produced by pickup of fields by the electrodes and leads during the recording of EEGs or ERs while the animal is being exposed. In addition to these cautions concerning methodology, it should be noted that most EEG studies are performed on heavily sedated animals, with phenobarbital as the usual drug. Hence the responses reported do not necessarily reflect those that would be expected in normal alert animals.

Tyazhelov (1977a) has discussed these problems and pointed out that, even for the coaxial electrode developed by Frey (1968), diffraction of EM waves is still a major source of error because of the electrode's metallic nature and large dimensions. Tyazhelov solved the problems by developing electrodes of high linear resistance (greater than 100 kilohms/m) and proper filtering of the recorded signal. This paper indicates an awareness in the USSR that questions may be raised about the validity of data and conclusions from many experiments involving animals with indwelling electrodes both in the USSR and the United States.

Dumanskij and Shandala (1974) reported changes in the biocurrents in the brain cortex of rabbits after 60 days exposure to RFR (50 MHz, 2.45 GHz, 10 GHz). Changes (vaguely specified as "an increase in the rhythm of slow waves and a decrease in the rhythm of intermediate and fast waves") were described at 10 microwatts/$cm^2$ and 1.9 microwatts/$cm^2$, but not at 0.01 microwatts/$cm^2$. Although the rather sketchy nature of their description precludes definitive critique of these results, it appears that the use of indwelling electrodes may have contributed artifacts, as described above.

In a more recent presentation, Shandala (1976) reported on observations of rabbits with implanted EEG electrodes, and again

claimed quite variable, but statistically significant EEG changes at 10 microwatts/cm$^2$ exposures (2.375 GHz) for 7 hr/day for 1 month. The same questions about implanted electrodes possibly causing artifactual data may be raised.

Goldstein and Cisko (1974) studied the EEGs of sedated rabbits ++ to determine whether RFR exposure would evoke arousal. They used 9.3 GHz RFR at 700 to 2,800 microwatts/cm$^2$. The EEG of each rabbit was recorded for about one hour. After the first ten minutes, the rabbit was sedated with sodium pentobarbitol. Five minutes later, the rabbit was exposed or sham exposed to the RFR for five minutes. The EEGs showed no arousal during RFR exposure but indicated alternations of arousal and sedation characteristics starting 3 to 12 minutes after exposure. Control animals also exhibited alternations having shorter arousal durations, rendering interpretation of these results difficult. These investigators were aware of the potential problem of metals in the pathway of the RFR and claimed to have mitigated it by using thin (0.01 inch) insulated, implanted stainless steel electrodes. It is unlikely that this reduced the artifacts significantly, if at all. They also stated that "under every day conditions, the EEG patterns of rabbits are quite variable. The animals oscillate between sedation and arousal unpredictably." This variability is another potential source of error in any experiments on the EEG of rabbits.

Chou (1978) used implanted carbon electrodes to avoid the artifactual problems associated with metal ones. Two groups of rabbits (six animals/group, three males, three females) were exposed to 2,450 MHz, 1,500 microwatts/cm$^2$ radiation for 2 hours daily for 3 months. One group received CW, the other pulsed radiation (10 microseconds, 100 pps, 1,500,000 microwatts/cm$^2$ pulse power density). A similar group of six animals was sham-exposed. No significant differences were observed between groups at the end of three months with regard to EEG and evoked potentials.

Kaplan (1978) (also discussed in Section C.7.11.3, p. C-70) reported that, from the beginning of the second trimester of pregnancy, 33 squirrel monkeys were exposed for 3 hr/day in + special cavity/cage modules to 2,450 MHz pulsed radiation at whole-body mean SARs equivalent to those resulting from plane-wave exposure to 100, 1,000, and 10,000 microwatts/cm$^2$ and compared with a group of eight pregnant sham-exposed monkeys. Eighteen of the exposed mothers were exposed with their offspring for an additional 6 months after parturition, and then their offspring were exposed alone for another six months after weaning. No statistically *significant differences* were found between exposed and nonexposed adults nor between exposed and nonexposed offspring on resting EEG and photically driven EEG parameters. (No chronically attached or indwelling electrodes were used.)

Rosenstein (1976) exposed one group of eight female rats to 10,000 microwatts/cm$^2$ at 425 MHz for 4 hours/day from the 12th

day after breeding until parturition, and another group of 12 dams to 5,000 microwatts/cm$^2$ at 2,450 MHz for 4 hours/day from the 6th day after breeding until parturition. The offspring were then exposed for 92 days. Control groups having the same population number were used for each frequency. Evaluation of the EEGs and the visual ERs of the offspring at 140 days of age indicated no significant difference between the exposed and control groups. (Again, indwelling electrodes were not used.)

In summary, the use of indwelling metallic electrodes in studies on the effects of RFR on the EEG and/or evoked potentials may be questioned as a procedure likely to introduce artifactual effects in the preparation under study, as well as in the recordings themselves. These artifacts may be minimized by use of electrodes appropriately designed from high resistivity materials. Experiments where such specially constructed electrodes were used, or where electrodes were applied after exposure, show no evidence of statistically significant differences in EEGs or evoked responses between control and RFR-exposed animals. +

### C.7.6 Effects on Behavior

The very large number and variety of behavioral studies in animals exposed to RFR makes the classification and interpretation of results very difficult. Also, the use of pulsed magnetrons or klystrons in some of the behavioral investigations may have inadvertently introduced auditory clues such as arcing noises and "pocks" produced by the incidence of RFR pulses on the walls of the exposure chambers. The analysis presented below represents a balanced selection of results from the recent literature on the subject. ++

#### C.7.6.1 Radiation Avoidance Responses

Mice exposed to RFR at 2.45 GHz (continuous wave), power levels not given, under conditions where they were relatively free to move around, tended to orient themselves so as to minimize the amount of energy absorbed (Monahan, 1978). In another study (Monahan, 1977a), rats were allowed to drink 10% sucrose solution for 15 minutes and were then exposed to 915 MHz radiation for 15 minutes in a waveguide at forward power levels of 5,000,000 to 19,000,000 microwatts (83,000-315,000 microwatts/cm$^2$). When the rats were offered a 10% sucrose solution 24 hours later, there was no evidence of avoidance of the sucrose, indicating that the sucrose was not associated with an intensely unpleasant experience. In a third study (Monahan, 1977b) mice were exposed to 2.45 GHz radiation at mean SARs of 46 mW/g (approximately 51,000 microwatts/cm$^2$) in an experimental arrangement where the mice could turn off the RFR repeatedly for 12 sec each time by interrupting a light beam. The mice responded by regularly turning off the light

beam, which is frequently taken, in the psychological literature, to constitute an escape or avoidance response.

### C.7.6.2 Acute Effects: Behavior Depression

Studies have been conducted on the effects of relatively high power densities of RFR on performance of trained tasks by animals (Sanza, 1977; de Lorge, 1977; D'Andrea, 1977; Lin, 1977; Gage, 1976; Galloway, 1976). Animals studied were rats, rhesus monkeys, and squirrel monkeys. All of the studies indicated that the radiation would suppress performance of the trained task, and that a radiation power density/dose threshold for achieving the suppression existed. Depending on duration and other parameters of exposure, the threshold power density for affecting trained behavior ranged from 5,000 to 50,000 microwatts/$cm^2$.

Rats exposed to pulsed radiation, 2.45 GHz at 6-11 mW/g (mean SAR), for single 30 minute sessions (Hunt, 1975), showed a temporary decrease in exploratory activity when placed in a test situation immediately after exposure. Similar results were found after the rats were subjected to pulsed RFR, 9.4 GHz at 700 microwatts/$cm^2$ (time not stated) (Gillard, 1975). On the other hand, chronic exposure to 3 or 10.7 GHz, 500 to 25,000 microwatts/$cm^2$, for total times ranging from 185 to 408 hours (Roberti, 1975), did not result in any change in spontaneous motor activity.

Rats exposed to relatively large doses of RFR showed decreased performance in a forced swimming test (Hunt, 1975). The effect appeared to be an early onset of fatigue after exposure.

### C.7.6.3 Chronic Effects

A study in rabbits and rats exposed to 3 GHz RFR at 1,000 to 10,000 microwatts/$cm^2$ for 60 min daily for up to six months (Lobanova, 1974) found a weakening of conditioned reflexes in the animals, as shown by increased latency or absence of response and failure to recognize the conditioned stimulus. The effect was intensified when inbred rats having a high level of excitability of the central nervous system were used, from which the author concluded that the RFR acted directly on the central nervous system.

In another study (Shandala, 1977b), rats exposed to 2.375 GHz radiation at 10 or 50 microwatts/$cm^2$, 7 hr/day for 90 days were tested periodically for learning an avoidance response, open field exploratory activity, and threshold of electric shock to the foot. Avoidance learning and foot shock threshold showed biphasic character of the responses. Avoidance learning was more rapid in exposed animals than in controls in the beginning of the study and slower at the end of the study. The foot shock threshold was

lower in exposed than in control animals in the beginning and higher at the end. The author attributes the results to an initial excitation of the central nervous system, followed by inhibition.

A third study (Mitchell, 1977) reported that rats exposed chronically to 2.45 GHz at 2.3 mW/g (mean SAR) over a 22-week period showed an increase in locomotor activity and a disturbance of differential responding to operant behavior. The changes were detected almost immediately after beginning the study.

### C.7.6.4 <u>Pulsed-RFR Effects on Natural Behavior</u> +

Exposure of rats to pulsed radiation (0.1-0.5 microseconds, 1,000/s) at 1, 1.3, or 1.5 GHz and peak levels of 50-200 microwatts/cm$^2$ inhibited an aggressive response in the rats, which is normally induced by acute pain (Frey, 1977). The pulse power density threshold of the response was between 50 and 100 microwatts/cm$^2$. Continuous wave exposure (power density not given) also blocked the aggressive response, but not as effectively as pulsed RFR. Pulsed RFR at a pulse power density level of 400 to 28,000 microwatts/cm$^2$ also caused a disturbance of motor coordination in a balancing test.

### C.7.6.5 <u>*Summary of Behavioral Effects*</u>

RFR does cause changes in behavior of animals, but most results have been obtained at power density levels in which the heat load is likely to have been significant, or local SAR values at specific locations were much higher than the mean SAR, as discussed in Section C.7.5.4, p. C-51. The studies on RFR avoidance were patterned after earlier studies 15 years ago using ionizing radiation. In the ionizing radiation studies the rats avoided the radiation when possible, and developed a strong aversion to saccharin solution when it was coupled with even modest radiation exposure (15-25 rad). In current experiments the rats did, indeed, avoid the RFR, but developed no aversion to the sucrose. The mean SAR of the avoided radiation was 27 to 46 mW/g, which for a 30-g mouse translates into a heat input of between 12 and 20 calories per minute. Therefore, based on these reports, RFR is not intrinsically aversive or noxious.

The inhibition of trained behavior in rats during or following RFR exposure seems to be consistently tied to threshold levels of + power density and duration of exposure. Although the number of + results reviewed is small, the inhibition threshold appears to be related to the complexity of the task and the type of discrimination required in performing it. The mechanism for behavioral inhibition is not known. The central nervous system may be involved, but at the power density threshold found for most

studies, it is unnecessary to postulate direct stimulation of the central nervous system.

Inhibition of exploratory activity generally involves the natural timidity of rats placed abruptly into novel situations. The results of the studies on voluntary and exploratory activity suggest that when exposure is coupled with a novel situation, the sense of novelty is heightened by the exposure (which is also a novel experience). The results in animals exposed over a period of time suggest that the animals become accustomed to the RFR as an experience.

The studies of Lobanova and Mitchell suggest that the disturbance of trained behavior found for acute exposure can also be pro- duced by chronic exposure, possibly at slightly lower power densi- ties. The results also suggest that if the power density and exposure time are sufficient to produce an effect on learned behavior, then the animal will not recover its normal behavior response while the RFR continues.

The results reported by Shandala and Frey are curious, and difficult to interpret in the context of other studies. Frey's results refer to innate behavior in the animal and imply that this behavior is perturbed by low power densities of RFR. The results of Gillard, obtained at 700 microwatts/cm$^2$, give some support to this conclusion. Shandala's results imply that there is a transition in behavioral effects during the course of chronic RFR exposure, an effect that was not found by Lobanova and Mitchell. Since Shandala's experiments involve continuous and repeated handling of the animals while they are being subjected to a minimal radiation stimulus, the experiment is highly susceptible to introduction of extraneous factors that then may become the principal determinant of results.

## C.7.7. Endocrinological Effects

Several studies of the effect of RFR on hormones levels in blood and glands have been reported. Most effects reported are related to the adaptation of the animal to the heat load or non-specific stress arising from exposure or other circumstances of the experiment.

The rate of release of thyroxine from the thyroid gland during RFR exposure was studied in dogs (Magin, 1977a, b). Measurement of the rate of release of thyroxine from locally exposed (2.45 GHz) glands <u>in situ</u> showed that exposure to 72,000 microwatts/cm$^2$ doubled the rate of release over a 2-hour period and exposure to 236,000 microwatts/cm$^2$ increased the rate of release ten-fold. Temperature of the thyroid gland was 39 deg C for the 72,000 microwatts/cm$^2$ exposure and 45 deg C for the 236,000 microwatts/cm$^2$ exposure. During the higher level of exposure, blood flow

through the thyroid increased by 70%. The authors believe that the elevated thyroxine release is a direct response of the gland to a rise in temperature.

A study of thyroid function in rats exposed whole body to 2.45 GHz CW RFR at 10,000 or 20,000 microwatts/cm$^2$ for 1 to 2 hours (Lu, 1977) showed a steady level of thyroxine in the blood, but a decrease in the level of circulating thyrotropin (TSH). After 4 to 8 hours, the TSH remained depressed and the thyroxine levels also fell. Exposure of rats to 1,000 microwatts/cm$^2$ for four hours caused a rise in rectal temperature and a transitory increase in blood thyroxine level.

A study of chronic exposure of rats exposed to RFR (2.45 GHz) also showed effects on thyroid function (Travers, 1978). Rats were exposed 8 hours per day for 7, 14, or 21 days to 4,000 or 8,000 microwatts/cm$^2$. Findings included decreases in serum levels of thyroxine, TSH, and albumin and increases in alpha-globulin and thyroxine-binding capacity. The changes in serum proteins were considered to be secondary metabolic effects of lowered thyroxine levels. Observed changes in thyroid function were dependent on power density and duration of exposure.

Studies of the adrenocortical response of rats exposed to RFR (2.45 GHz) have shown a time-power density threshold for effect (Lotz, 1976 and 1977). Rats exposed for 30 or 60 min showed increases in the plasma corticosterone level only when the power density was 50,000 microwatts/cm$^2$ or more. Rats exposed for 120 min showed increases in plasma corticosterone at power densities of 20,000 microwatts/cm$^2$ or more. There was a strong correlation between plasma corticosterone rise and colonic temperature rise. Exposure of hypophysectomized rats or rats treated with dexamethasone produced no increase in plasma corticosterone, indicating that the increase was mediated through the anterior pituitary rather than by direct stimulation of the adrenal gland.

Another study of plasma corticosterone levels following RFR exposure (2.45 GHz, 24 hours, power density not specified) showed that the increased level was transient, lasting only a matter of minutes (Deschaux, 1977). By contrast, the level of plasma testosterone rose following exposure and remained elevated for several days.

Studies of the effects of RFR (2.45 GHz) on plasma levels of pituitary growth hormone showed a response similar to that of corticosterone, but with reversed direction (Lotz, 1977; Michaelson, 1975). For 30 or 60 min exposures, the growth hormone level was decreased only when the power density was equal to or greater than 50,000 microwatts/cm$^2$. For 120 min exposures, the growth hormone level was decreased when the power density was 13,000 microwatts/cm$^2$ or more.

Another study of the effect of RFR (2.86-2.88 GHz) on plasma corticosterone confirmed the power density-time threshold effect (Mikolajczyk, 1974). Exposure of rats for 15 minutes at 10,000 microwatts/cm$^2$ had no effect on corticosterone levels of either the blood plasma or the adrenal gland. Exposure of rats 2 hours/day at 10,000 microwatts/cm$^2$ for 35 days caused a decrease in the pituitary level of luteinizing hormone (LH), and irregular effects on the follicle-stimulating hormone (FSH). Exposure of rats a single time at 10,000 microwatts/cm$^2$ for 6 hours caused an increase in both LH and FSH. In a follow-up study (Mikolajczyk, 1975), exposure of rats 6 hours/day at 10,000 microwatts/cm$^2$ for 35 days also caused an increase in LH, but had no effects on FSH or growth hormone. The results suggest that duration of exposure over a single day, rather than the cumulative effect of serial exposure, is the primary determinant of effects on LH and FSH.

In summary, the effects of RFR exposure on endocrine function in mammals is generally consistent with both immediate and long-term responses of the animals to thermal load and to nonspecific stress, which can also arise from thermal load. The immediate response of the thyroid of the dog to local RFR exposure is an increase in thyroid hormone production, presumably resulting from the increased metabolic rate in the gland. The long-term response of animals to whole-body RFR exposure at thermally significant power density is a decrease in the level of pituitary thyrotropic hormone in the blood plasma, followed by a decrease in the level of thyroxine. This response is homeostatically appropriate to the increased heat load, requiring a lower level of metabolism, and would be expected to appear rather promptly in an animal as small as a rat, where the thermal load/metabolic rate balance is somewhat labile.

Changes found in plasma levels of corticosterone and growth hormone are typical reactions of animals to nonspecific stress; indeed, great care is required in performing the experiments to ensure that the changes in hormone level do not result from stress caused by handling of the animals or novelty of the experimental situation.

Changes in level of LH in the pituitary may be either a response to stress or a metabolic adaptation to heat load. The overall results, showing that the response depended on duration of exposure each day, suggest the latter explanation.

The changes in level of plasma testosterone following a 24-hour exposure to RFR are difficult to evaluate in the absence of information on the power density level. If the level were sufficient to inhibit spermatogenesis or deplete spermatogonia, the increased testosterone level could be a compensating mechanism to restore gonadal function. The spermatogonia of the testes are rather more sensitive to heat than other cells, and protracted

exposure (9.27 GHz, 100,000 microwatts/cm$^2$, 4.5 min/day, 5 days/week) causes testicular atrophy in mice, beginning after 4 months of exposure (Prausnitz, 1962, also cited in Sections C.7.8.4, p. C-62, and C.7.11.1, p. C-68, and C.7.11.3, p. C-69). Hormonal measurements were not made in this study. However, a study of men occupationally exposed to RFR at levels of up to several hundred microwatts/cm$^2$ (Lancranjan, 1975) showed slightly reduced sperm counts, but normal plasma levels of 17-ketosteroid and gonadotropin, indicating that there was no basic damage to the testes. Since sperm counts can be influenced by diet, age, temperament, sexual activity, personal problems in employment and social life, and other factors, the significance of the findings is not clear.

## C.7.8 Immunological Effects

A number of studies have been reported on the effects of RFR exposure on the immune systems of experimental animals. The results have been somewhat contradictory, with some studies indicating stimulation and others suppression of the immune system. Because of the complexity of the mammalian immune system and the variety of test systems available, it seems desirable to discuss the observed effects by separate types of experiments.

### C.7.8.1 In Vitro Studies

These studies have been conducted to determine whether RFR exposure can induce lymphoblastoid transformation of lymphocytes in cell culture. Blast-transformation of cultured human lymphocytes was reported by Stodolnik-Baranska (1967) following exposure of the culture to 10-cm (3 GHz) RFR at 7,000 or 14,000 microwatts/cm$^2$. In an attempt to repeat the study, Czerski (1975) also reported evidence of blast-transformation in human lymphocytes exposed to RFR, but stated that the results were poorly reproducible. In another publication (Baranski, 1976), blast transformation of human lymphocytes was reported following exposure with 3-cm (10 GHz) RFR at 5,000 to 15,000 microwatts/cm$^2$. The report stated that power density levels below 5,000 microwatts/cm$^2$ were ineffective, that power density levels above 20,000 microwatts/cm$^2$ only killed the cells, and that between 5,000 and 15,000 microwatts/cm$^2$ the blast transformation depended upon stopping the exposure at the moment when the temperature of the medium reached 38.5 deg C. Another study (Smialowicz, 1976) reported complete failure to induce blast transformation in lymphocytes derived from mouse spleen by exposure to 2.45 GHz RFR at 10,000 microwatts/cm$^2$ for 1, 2, or 4 hours. The temperature during the exposure remained stable, and there was no evidence of cell death as a result of the exposure.

The seemingly contradictory findings in the above studies may reflect some differences in the methodology and materials in the separate experiments. Stodolnik-Baranska identified blast-

transformation by histological observation; Czerski, by a macrophage migration inhibition test; and Smialowicz, by measuring incorporation of $^3$H-thymidine into DNA. In addition, the studies reported by Stodolnik-Baranska, Czerski, and Baranski used human lymphocyte cultures, while that of Smialowicz used mouse spleen lymphocyte cultures. The most consistent conclusion is that the blast transformation of lymphocytes depends -- perhaps in a complex way -- on temperature effects in the medium, and there is no evidence of ability of the RFR to stimulate the cells directly to undergo transformation.

### C.7.8.2 In Vivo Studies: Acute Exposures

Relatively intense RFR exposure over short periods of time has been reported to produce specific changes in cell proliferation and differentiation in the immune systems of experimental animals. Exposure of mice to 2.45 GHz RFR at 100,000 microwatts/cm$^2$ for 5 minutes (Rotkovska, 1975) caused an increase in the number of circulating lymphocytes in the blood at 4 and 7 days after exposure. The effect was associated with an increase in the number of nucleated cells in the spleen over the same time period. Exposure of mice to 2.6 GHz RFR at 10,000, 15,000, and 20,000 microwatts/cm$^2$ for various periods of time, followed by innoculation with sheep red blood cells (SRBC) (Krupp, 1977) resulted in an increase in the number of SRBC-antibody producing cells in the spleen, as compared to nonexposed SRBC-innoculated mice. The effect was obtained whenever the exposure conditions resulted in a 3 deg C rise in rectal temperature, and it could be elicited by administration of cortisone, instead of RFR exposure, indicating that the effect was mediated through the pituitary-adrenal axis. In other studies (Wiktor-Jedrzejczak, 1977a, b) exposure to 2.45 GHz RFR at 10-20 mW/g (11,000-22,000 microwatts/cm$^2$) for 30 to 45 minutes resulted in changes in the number and distribution of cell types in the spleen. Both the frequency of cells bearing a receptor for the Fc portion of the immunoglobulin molecule and those bearing a receptor for complement increased. The results indicated a selective stimulatory effect of the RFR on these subpopulations of B lymphoid cells.

### C.7.8.3 In Vivo Studies: Chronic Exposures

In a study of the effects of RFR on direct immune response to antigenic stimulation (Czerski, 1975) mice were exposed to 2-hour daily sessions of 2.95 GHz pulsed RFR at 500 microwatts/cm$^2$ for 6 or 12 weeks, and then injected with sheep red blood cells. After 6 weeks of exposure there was a large increase, as compared to unexposed controls, in the relative numbers of lymphoblastoid cells and plasmocytes and the absolute number of antibody-producing cells in the lymph nodes of exposed animals. The results were essentially similar to those of Krupp, cited above.

After 12 weeks of exposure, however, the lymphoid cell response had returned to the level of the unexposed animals.

More general studies of the effects of chronic exposure to RFR on the immune system have also been performed. Exposure of guinea pigs and mice to 2.95 GHz pulsed RFR at 1,000 microwatts/cm$^2$ for 4 hours/day for 14 days (Czerski, 1974) resulted in shifts in the circadian rhythm of a number of mitotic figures in cells of the bone marrow. Exposure of rats to 425 MHz RFR at 5,000 microwatts/cm$^2$ for 4 hours/day daily from prebirth through age 40 days (Smialowicz, 1977) resulted in a neutropenia and leukocytosis in the rats exposed to 425 MHz, but not to 2.45 GHz. Both animals showed enhanced response of lymph node lymphocytes to stimulation with T- and B-lymphocyte mitogens. In contrast to this finding, another study (Shandala, 1976, 1977a) reported that exposure of rats to 2.375 GHz RFR at 500 microwatts/cm$^2$, 7 hr/day daily for periods up to 30 days resulted in a "downward trend" in numbers of mitogen-responding T-cell lymphocytes. Exposure at 50 and 10 microwatts/cm$^2$ resulted in an initial increase in T-cell lymphocytes, followed by a decrease. The same study claimed that at 500 microwatts/cm$^2$, autoallergenic activity was observed. Another study from the same laboratory (Vinogradov, 1975) reported that similar exposure of guinea pigs at 1 to 50 microwatts/cm$^2$ resulted in leukocytosis, neutrophilic and eosinophilic granulocytosis, and increased complement titer and phagocytic activity of granulocytes in the circulating blood. Finally, a study of rabbits exposed to 2.45 GHz RFR at 10,000 microwatts/cm$^2$ for 23 hours/day for 6 months (Guy, 1976b) showed a decrease in numbers of spleen lymphoid cells responding to pokeweed mitogen, but no change in numbers responding to phytohemagglutinin or concanavalin A, indicating a possible suppression in the B-cell lymphocytes after prolonged exposure.

### C.7.8.4 <u>Health and Disease</u>

A number of studies that have been conducted relate directly or indirectly to the question of whether the immunological effects of RFR exposure have any significance for disease resistance. Exposure of rabbits to 3 GHz RFR at 3,000 microwatts/cm$^2$ for 6 hours/day for 6 or 12 weeks resulted in some changes in the immunological response of the animals to experimental infection with <u>Staphylococcus aureus</u> (Szmigielski, 1975). Exposed animals showed a depression in peripheral granulocyte count, a depression in the granulocyte reserve that could be mobilized by bacterial endotoxin, and an increased lysozyme activity of serum. However, none of the animals died from the infection. Another study considered the possibility that RFR-stimulation of the immune system might be beneficial in treatment of infection. Exposure of mice to RFR (no frequency or intensity reported), 6 hours per day for 6 days (Pautrizel, 1975), was reported to protect mice against an otherwise fatal experimental infection with <u>Trypanosoma equiperdum</u>.

Finally, long-term exposure of mice to 9.27 GHz RFR, 100,000 microwatts/cm$^2$, 4.5 min/day (Prausnitz, 1962, also cited in Sections C.7.7, p. C-60, C.7.11.1, p. C-68, and C.7.11.3, p. C-69), was found to protect mice against a pneumonia infection inadvertently introduced into the colony 9 months into the study.

### C.7.8.5 <u>Conclusion</u>

There is abundant, if conflicting, evidence that exposure to RFR affects the immune system of mammals. Studies <u>in vitro</u> indicate that if RFR directly stimulates cells of the immune system, the effect is mediated through temperature changes. Studies of acute exposure <u>in vivo</u> indicate that RFR effects on the immune system may be mediated through the pituitary-adrenal axis, but the possibility of a direct effect of the radiation on the cells of the immune system is not excluded. All acute effects have been elicited at power density levels that are in the range of thermal effects.

Chronic exposure to RFR is purported to elicit effects on the immune system at power density levels that are sufficiently low (10s to 100s of microwatts/cm$^2$) for the effects to be unlikely to be the result of simple temperature rise. The overall nature and significance of the effects is not yet understood, nor have individual reports been independently verified. The study of Czerski suggests that RFR causes a temporary change in the responsiveness of the immune system that returns to normal levels under continued exposure; this result suggests that there may be a phase of biological adaptation to the RFR. The studies of Shandala and Vinogradov report what are essentially opposite effects from the same conditions and durations of exposure in different species of animals. Since their studies were not continued beyond 30 days, it is not yet known whether their findings represent temporary shifts in the immune system prior to developing biological accommodation.

There is presently no evidence that reported RFR effects on the immune systems of animals at average power densities less than 1,000 microwatts/cm$^2$ would occur in humans or that such effects would be hazardous to human health. The only study that even suggested that RFR exposure might inhibit disease-combatting ability was conducted at power-density levels in the thermal region (3,000 microwatts/cm$^2$), and the animals in this study all survived. Other studies suggested that the RFR might even be beneficial. If chronic low-level RFR exposure did impair the ability to resist disease, then a relatively high rate of infectious diseases should occur among people occupationally exposed to RFR, and it is highly unlikely that this would not have been noticed. The possible low-level effects are taken seriously in the USSR because Soviet doctrine on environmental and occupational health (Zielhuis, 1974) holds that any biological effect of any environmental agent is considered to be an unacceptable hazard

to man, regardless of its real medical significance. (This is discussed in Section C.3, p. C-7.) Under such a doctrine, Shandala may find immunosuppressive effects and Vinogradov may find immunostimulatory effects under the same conditions, and the Soviet Ministry of Health may regard either of these findings or both of them together as sufficient reason for setting exposure standards at a level where no effect is likely.

### C.7.9 Biochemical and Physiological Effects

A number of reported biochemical and physiological effects of RFR that can be attributed to known adaptive mechanisms of animals to heat or stress have been noted in other sections of this EIS. + Other observations, e.g., body weight and hematological observations, have been noted in connection with studies of chronic exposure, where such measurements are commonly made. This section is addressed to other studies of metabolism, blood chemistry, and DNA structure that are not reported elsewhere.

A study of mice exposed to 2.45 GHz RFR in the mean SAR range + of 21-31 mW/g (23,000-33,000 microwatts/cm$^2$) showed that the mice decreased consumption of oxygen in response to the added heat load (Ho, 1977). Ability of the animals to compensate for the added heat load was partly determined by the size of the holding container; narrowly confined mice compensated more poorly than less restrained mice. A study of germinating peas (Carley, 1976) exposed to 3.3 GHz RFR at 5,000, 3,500, 2,000, 1,000, and 500 microwatts/cm$^2$ showed a decrease in oxygen consumption by the peas that was approximately related to power density level, with 500 microwatts/cm$^2$ showing no effect. The author claimed the effect to be nonthermal, but another study (Grunewald, 1978) found a selective increase in the internal temperature of the peas, as compared to surrounding air, during the exposure. This study noted that the metabolic pathway affected by the RFR was the starch-to-glucose path, but the evidence indicates that the effect was probably thermal in nature. At a somewhat lower level of biological organization, RFR exposure was found to have no effect on the metabolic rates of Ehrlich ascites tumor cells in culture (Plontek, 1977), isolated rat liver mitochondria (Elder, 1975), or cell membrane-bound enzyme systems of the rat (Allis, 1977).

A study of serum triglyceride levels in mice exposed to 2.35-to-2.50 GHz RFR at 3,000 to 4,000 microwatts/cm$^2$ continuously for 60 hours (Deficis, 1977) showed that the serum triglyceride level rose in the exposed animals. Changes were also observed in levels of serum beta-lipoproteins. A report from Czechoslovakia (Pazderova, 1974) (see Section C.7.1, p. C-33) noted that workers in television and radio transmitting stations showed changes in blood proteins, with decreased albumin and increased alpha and beta globulins, as compared with values for people not working there. Power density levels were not given, but the author noted

that although the changes were statistically significant, the protein levels were still within the normal physiological ranges for the age and physical condition of the subjects. A report from the USSR (Gabovich, 1977) noted that rats exposed to 2.37 GHz RFR, 10-1,000 microwatts/cm$^2$, for 8 hr/day for 4 months, showed changes in turnover of trace elements, notably copper, molybdenum, iron, and manganese. The reported changes appeared to be irregularly dependent on power density, with increases in tissue content of elements being reported at the higher levels and decreases at the lower levels.

Studies *in vitro* at UHF frequencies (Krey, 1978) have shown that calf thymus DNA showed a relaxation effect that appeared to depend upon configurational parameters of mononucleotides within the molecule. Power density levels were not stated.

*In vivo* studies of the effect of RFR exposure on the DNA structure of the mouse testes (Varma, 1977) have also been reported. Exposure to 1.7 GHz RFR for 30 minutes at 50,000 microwatts/cm$^2$ resulted in an increase in the asymmetry ratio, a hyperchromic decrease, and a decrease in the melting temperature. The author postulates that the effects noted were a result of RFR-induced strand separation -- a highly credible conclusion in view of the high power-density levels employed. This work was performed in parallel with the studies reported in Section C.7.2, p. C-36, on the possibility of dominant lethal mutations being induced by the exposure.

In summary, effects of RFR on metabolic rate of animals appear to reflect normal physiological changes in response to heat load. Effects reported in germinating seeds appear to reflect changes in pathways of glucose metabolism, but their significance is not known. There were no effects of RFR on oxidative metabolism of cultured cells, mitochondria, or enzyme systems.

RFR is reported to influence the levels of plasma lipids and proteins *in vivo*. The experimental results in mice may be secondary to responses to stress, as the thermal load in the experiment was not insignificant. The results of the studies in Czechoslovakia and the USSR on the changes in plasma proteins and mineral trace elements are interesting, but difficult to evaluate. The Czech study observed that the workers examined appeared to be in good health, so the significance of the findings for health of the population is presumably minimal. The study from the USSR notes opposite effects from different power levels; this finding suggests the possibility of a transient change in response to the RFR.

The *in vitro* studies on effects of RFR on DNA appear to be primarily oriented toward investigation of the macrostructure of DNA, and do not *per se* suggest an effect under ordinary conditions *in vivo*. The *in vivo* studies in the mouse clearly reflect thermal

effects of the RFR exposure. For the high power-density levels used, even the observed effects are minimal in degree.

### C.7.10 Cellular Effects

Guy (1977) has described the development and characteristics of a transmission line cell-culture sample holder suitable for use in exposing a sample of cells in a culture medium for short periods to controlled broadband radiofrequency fields and controlled temperatures. Guy indicates that:

> "In analyzing the data of many earlier experiments involving the effects of EM fields on cell cultures, blood samples and solutions containing microorganisms, one can raise questions concerning the exact magnitude of the fields and the temperatures of solutions during exposure. . . . Samples are often placed in fields of known strength and power density, but, due to the complex shape of vessels that hold the samples, the actual fields acting on the cells and the temperature in the sample are unknown. These unknowns make it difficult in many cases to determine whether observed effects are due specifically to the fields, or simply to a rise in temperature."

These comments are relevant to evaluating the results and conclusions of the several papers reported in this section and other sections. Michaelson (1970) made similar points with regard to evaluating studies on isolated cell systems, emphasizing that the interpretation of the biological results, e.g., cytogenetic effects, is difficult and does not necessarily lead to meaningful conclusions because of the many variables in tissue culture technique, e.g., influence of heat, viruses, chemicals, etc., that must be taken into consideration. In his most recent review, Michaelson (1978) has again emphasized the problems of interpretation of in vitro studies.

Riley (1978) reported on the application of the Guy cell-culture exposure system to neoplastic cells. Riley had previously established that differences in tumor latency periods are a linear function of the number of viable neoplastic cells injected into appropriate recipient animals. Any significant RFR-induced damage to viable neoplastic cells is reflected as an increase in tumor latency period. Using this bioassay, Riley found no significant differences in tumor latency among 0, 500, and 1,000 V/m of 30 MHz ++ RFR applied for 20-minute periods, with temperature of the culture medium maintained at 43 deg C by recirculating it through a constant temperature bath. (The free-space-equivalent power densities are approximately: 0; 66,000; and 270,000 microwatts/cm$^2$, respectively.)

There have been several studies on the effects of RFR on lymphocytes in cell culture. Discussions of selected examples of

these studies are contained in Section C.7.8.1, p. C-60.

Changes of cell membrane permeability have also been attributed to RFR (Baranski, 1974). More recent publications (Liu, 1977; Peterson, 1978) have failed to find effects, apart from those resulting from RFR-heating. Janiak (1977) likewise reported no significant differences in the sequence and time-course of cell membrane injury between cells heated in a water bath and those heated with RFR (2,450 MHz).

Corelli (1977) investigated the effects of 2.6-4.0 GHz RFR on colony-forming-ability (CFA) and molecular structure (determined by infrared spectroscopy) of <u>Escherichia</u> <u>coli</u> <u>B</u> bacterial cells in aqueous suspension. Cells were exposed for 10 hours at SARs of 20 W/kg (this can be estimated to be approximately equivalent to 50,000 microwatts/cm$^2$ plane-wave exposure). No RFR-induced effects on either CFA or molecular structure were observed.

In summary, most of the results of experiments presented here on the effects of RFR on cell cultures are difficult to interpret because of questions concerning the exact magnitude of the fields and the temperatures during exposure. The available studies provide no evidence of effects other than those that can be attributed to an RFR-heating effect at levels far greater than those calculated to exist outside the PAVE PAWS exclusion fence.

## C.7.11 Other Effects

Various other purportedly hazardous effects have been attributed to RFR. These effects will be considered briefly in this section.

### C.7.11.1 Cancer Studies

A technical report published recently (Dwyer, 1978) by the National Institute of Occupational Safety and Health (NIOSH) reviewed the evidence in the literature concerning the possible carcinogenic properties of RFR. Only two papers in the literature cited made direct reference to carcinogenesis by RFR.

The first paper (Zaret, 1976) stated that the incidence of cardiovascular disease and cancer in the North Karelian district of Finland had increased recently. This district borders on a region of the USSR that has large radar installations forming part of that nation's missile warning system. Zaret asserted that increase in cardiovascular disease and cancer in Finland is due to the RFR from USSR installations. No documentation of the alleged increase in these diseases is given. Zaret mentioned a study of

the problem sponsored by WHO, but did not cite it. Three WHO publications specifically dealing with potential hazards of RFR (WHO, 1971; WHO, 1973, Suess, 1974) made no mention of the problem in North Karelia. The statements of Zaret are not supported.

The second paper reviewed in the NIOSH document (Prausnitz, 1962 -- also cited in Sections C.7.7, p. C-60, C.7.8.4, p. C-63, and C.7.11.3, p. C-69) reported a somewhat higher percentage of leucosis in mice exposed chronically to RFR. The authors interpreted the finding to indicate a higher percentage of leukemia in the irradiated mice. Technically speaking, leucosis (more properly spelled leukosis) means an increase in the count of white blood cells over that found normally. Such a condition can occur in leukemia; it can also occur in the presence of infections or abscesses, both of which were found in the colony during the course of the experiment. Proper diagnosis of leukemia requires histopathological assessment of bone marrow, lymph node, and spleen specimens, and the methods and criteria of diagnosis used in this study are inadequately described. The increased incidence of leucosis was found among animals that died during the course of the exposure. Pathology samples from many of these animals were lost because of tissue autolysis, and the diagnostic reliability of the remaining animals is questionable. A number of mice were also sacrificed during or following the RFR exposure, and were assessed for the presence of "leucosis." Among these animals, 18 out of 87 irradiated and 5 of 29 control mice had "leucosis." The difference is statistically insignificant. Thus, even if adequate diagnostic criteria were used (which is questionable), there is no evidence that the RFR caused leukemia in the mice.

In addition to the two papers reviewed above, the NIOSH document reviews without critical comment a number of papers summarizing other biological effects of RFR, including genetic, cytogenetic, immunological, and endocrine effects reviewed elsewhere in this appendix. No discussion is presented on the power density threshold aspects of these findings.

In the final paragraph, the NIOSH document states: "At present, the evidence linking RF/MW (radiofrequency/microwave) radiation to carcinogenesis is speculative and circumstantial." A more positive statement is that there is no scientific evidence at present that relates RFR to carcinogenesis.

### C.7.11.2 Cardiovascular Studies

Pulsed RFR may have effects on artificial cardiac pacemakers by overriding the function signal from the heart. These effects are treated in Section D.3.2.1, p. D-64. Apart from pacemaker effects, RFR has been reported to cause bradycardia or tachycardia in a variety of experimental situations.

A report from the USSR (Gordon, 1974) stated that bradycardia could be produced by exposure of experimental animals to RFR (frequency not specified) in the power density range of 1,000-10,000 microwatts/cm$^2$. Mice, rats, rabbits, and cats were mentioned in the report, but it is not certain which species were used in the cardiovascular studies. A study in the United States (Kaplan, 1971) did not find any effects on the heart rate of rabbits from exposure to 2.4 GHz RFR at 10,000 microwatts/cm$^2$ for 20 minutes. Increasing the power density to 40,000 microwatts/cm$^2$ increased the respiration rate, and increasing it to 80,000 microwatts/cm$^2$ increased the body temperature. Only when the power density level reached 100,000 microwatts/cm$^2$ did the heart rate increase. It is likely that the increase observed at 100,000 microwatts/cm$^2$ represented a compensatory physiological adjustment to the heat load being experienced by the animals.

Other studies have been conducted on the effects of RFR on heart rate in turtles and frogs. Turtles exposed to 960 MHz radiation at 100 to 10,000 microwatts/cm$^2$ showed no effect on heart rate (Flanigan, 1977). Frogs exposed to 5 microsecond pulses of 1.25 GHz RFR that were timed by electronic feedback to coincide with the rise of the R-wave of the electrocardiogram exhibited tachycardia (Eichert, 1977), but when the pulses were timed to coincide with the T-wave the results were inconclusive. Therefore, under very precisely controlled conditions of exposure, RFR could function as a cardiac pacemaker.

From a medical viewpoint, bradycardia and tachycardia allegedly produced by RFR is only of marginal interest. The only report that we have found that claims any significant increase in cardiovascular fatalities as a result of RFR exposure is that of Zaret cited above, Section C.7.11.1, p. C-67. The lack of supporting evidence in the paper has already been noted.

### C.7.11.3 General Health; Chronic Studies +

Various studies have been conducted on effects of chronic, long-term exposure of animals to RFR. Because of technical problems it is very difficult to expose animals on a round-the-clock basis; hence, many of the studies have been performed by exposing the animals for some fixed duration each day. Although this +
design may not be completely satisfactory, it does address the question of cumulative effects of the RFR.

The study by Prausnitz (1962) has already been cited in Sections C.7.7, p. C-60, C.7.8.4, p. C-63, and C.7.11.1, p. C-68 +
of this EIS. The study involved exposure of mice to pulsed 9.27 +
GHz RFR at 100,000 microwatts/cm$^2$ average power density for 4.5 +
minutes per day 5 days/week for 59 weeks. Each day's exposure was equal to one-half of the acute $LD_{50}$ for the animals (i.e., one half of the dose that would prove lethal to 50% of animals exposed to it). Atrophy

of the testes was observed in exposed mice -- not surprising in view of the power density. At the end of the 59 weeks of exposure, 50% of the control mice had died, as compared with 35% of the exposed mice, i.e., the exposed mice lived longer.

Another study (Spalding, 1971) involved exposure of mice to 800 MHz RFR at 43,000 microwatts/cm$^2$ for 2 hours/day for 5 days/week for 35 weeks. After completion of the exposure the mice were observed for the remainder of their life spans. Five of the mice died during the exposure, and these deaths were attributed to thermal effects caused by faulty positioning of the animal holders. The mean life-span of the remaining exposed mice was not significantly different from that of the controls. White blood cell (WBC) counts showed occasional, but unsystematic differences between exposed and control animals, but other parameters measured (erythrocyte count, body weight, voluntary activity) did not differ between exposed and control animals. Since WBC counts are extremely labile, the differences reported are probably insignificant.

Another study (Baum, 1976) entailed exposure of rats to electromagnetic pulses (5 pulses/sec, 447 kV/m) continuously over a period of 94 weeks. The spectrum of the pulses corresponded very approximately in its center frequency to the PAVE PAWS frequency band (420-450 MHz). There was no effect of the pulses on blood chemistry, blood count, bone marrow cellularity, fertility, embryological development, cytology, histopathology, or occurrence of cancer even after 200 million pulses.

Chronic exposure studies have also been carried out where the period of exposure and observation was more limited in time. Exposure of rats to 2.4 GHz RFR at 5,000 microwatts/cm$^2$, 1 hour/day for 90 days (Djordjevic, 1977) had no effect on hematologic parameters during or following the exposure period and no effect on body weight or histological appearance of tissues. A similar study in mice (Koessler, 1977) reported a similar absence of effect. Another study currently in progress (Chou, 1978) involves exposure of rabbits to 2.45 GHz RFR, CW or pulsed, at 1,500 microwatts/cm$^2$ average power density for 2 hours/day for 3 months. Ongoing measurements of hematological parameters, electroencephalographic patterns, and lenses of the eyes show no effects of the exposure on any of these functions.

Occasionally, chronic exposure to RFR has been associated with death of the subject animals. The cause of death is not reliably known, and its relationship to the experimental procedures is uncertain. In one study (Shore, 1977) rats exposed in utero from day 3 through 19 of gestation to 2.45 GHz RFR at 10,000 microwatts/cm$^2$, 5 hours/day were found to have a higher neonatal mortality than unexposed animals. The authors discount the mortality data because the experiment was not designed to measure mortality. In another study (Kaplan, 1978) (also discussed in Section C.7.5.5, p. C-53, squirrel monkeys exposed to RFR in

utero during the second and third trimester of pregnancy and continuing for 12 months after birth (2.45 GHz pulsed, 10,000 microwatts/$cm^2$ average power density, 3 hr/day) showed a high infant mortality (4 out of 5 animals, as compared to 0 out of 8 in controls). However, infant mortality is historically common among these animals, and the distribution of mortality over all of the different exposure level groups was only marginally significant because of the small number of animals used in each group. In a third study (Stavinoha, 1976), mice and rats were exposed to 19-MHz RFR in a near-field synthesizer for 40 min/day for 5 days. There was a selective high mortality of male mice, but not female mice. There was no selective mortality for male and female rats. Thermal heating to levels equivalent to that produced by the RFR was found to produce the same effect. Finally, a group of Polish engineers (Bem, 1975) observed a pair of sparrows that built a nest near the feedline of an operating very-high-power broadcast antenna and raised a brood of young. To conform with the Polish RFR exposure standards, authorities had located all previous human inhabitants of the area outside a 10-km radius from the antenna. No deleterious effects were observed on either the adult sparrows or the young despite exposures to fields in the kilovolts per meter range, and in the proper course of time the young sparrows matured and flew away.

#### C.7.11.4 Summary

In summary, there is no credible evidence that RFR causes cardiovascular disease or cancer. There is no evidence at present in the scientific literature to suggest the possibility that it could be a contributing cause to these diseases. A number of studies of chronic exposure of animals to RFR fails to show any evidence of cumulative effect of the RFR or of deleterious consequences that can realistically be attributed to the RFR on any basis other than its heating effect. Power densities sufficiently high to cause heating far exceed the densities from PAVE PAWS beyond the exclusion area.

## C.8 Unresolved Issues

The potential biological effects of RFR from the PAVE PAWS facility have been assessed out of necessity from existing studies in the 10 MHz to 18 GHz range, with recognition that the negative findings reported in some studies may have been obtained because the investigations were poorly conducted. The conclusion is that the RFR will have no perceptible biological effects on the human population in the vicinity of PAVE PAWS. The fundamental bases for this conclusion are the evidence of power density thresholds for many of the reported effects; the considerable difference between the power densities in the neighborhood of PAVE PAWS and those at which biological effects have been reported -- amounting

in most cases to between 3 and 6 orders of magnitude; and the absence of reliable evidence of objective human disease in persons exposed to RFR in the past. The substantial weight of these considerations allows the conclusion of absence of bioeffects from the RFR of PAVE PAWS regardless of the problem of extrapolating experimental results from animals to humans, the point that most animal research is usually not conducted using exposures extending over most of the normal lifespan of the animal, and the inadequacy of epidemiological studies in humans. ++

The problem of extrapolation of experimental results from one frequency to another and from one animal species was discussed briefly in Section C.4, p. C-9. Some progress has been made in the development of theoretical models for extrapolating from one frequency to another (as discussed in Section C.6.1, p. C-18) but the present level of knowledge is inadequate for predicting precisely the biological effects of RFR in humans from studies performed in mice or other experimental animals.

A number of investigations involving chronic exposures of animals to RFR have been conducted at power densities well above the levels of general population exposure from PAVE PAWS. Similar studies in which animals are continuously exposed over most of their lifespans may provide additional information regarding effects of chronic exposure. ++

The existing epidemiological studies were reviewed in Section C.7.1, p. C-27. The studies were competently performed, but they are all retrospective in nature, i.e., undertaken after the occurrence of RFR exposure, and they suffer from certain inherent defects of retrospective studies, such as uncertainty about the level and duration of exposure, possible selective factors in locating members of the exposed population, and the difficulty in constructing adequate control groups. Prospective studies, in which the exposed population is identified before exposure begins, would eliminate such defects and provide a better basis for conclusions about effects of RFR on human health. +

The points above remain unresolved issues in the assessment of bioeffects of RFR, though they do not affect the conclusions reached in this EIS. ++

## C.9 PAVE PAWS and Safety to Human Populations

(This summary is fully covered in Section 3.1.2.1.9, p. 3-60.)

## C.10 Other Viewpoints ++

(This summary is fully covered in Section 3.1.2.1.10, p. 3-61.)

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## Appendix D

## ELECTROMAGNETIC INTERFERENCE AND HAZARDS TO SYSTEMS

### D.1 Introduction

This appendix presents an analysis of the potential effects of the operation of the PAVE PAWS radar system at Otis AFB on other systems. The systems considered include those that use the electromagnetic spectrum, as well as others that are not designed to be users of the electromagnetic spectrum, but may nevertheless be susceptible to the energy radiated by the radar. Systems in the first group include telecommunication systems and other radars, all of which are designed to sense electromagnetic energy. Systems in the second group include cardiac pacemakers and electroexplosive devices (EEDs), which may inadvertently be subjected to the radar energy; excessive exposure of such systems may create hazardous situations.

Section D.2, p. D-4, of this appendix describes the frequency and time behavior of the radar. Basic to an analysis of the effects of any EMR emitter on other systems is an understanding of the characteristics of the emission. PAVE PAWS is a complicated system operating under computer control, according to preprogrammed operating algorithms. Its beams do not sweep; rather, they probe from one azimuth to another in a pseudorandom manner. PAVE PAWS has a repertoire of pulse widths, and it continually switches frequency. The operation is not predictable from moment to moment, because the radar will alter its routine surveillance operation to provide tracking data on some of the objects it detects, and also because it may decide not to use some of its available frequencies if they are experiencing interference. At all times, it is responding to outside influences according to well-defined rules programmed into the computer.

Section D.3, p. D-16, analyzes incidental electromagnetic effects of PAVE PAWS. It is divided into two subsections. In Section D.3.1, p. D-16, we discuss other telecommunication systems, and in Section D.3.2, p. D-64, we discuss three inadvertent receivers of energy. In both sections, the approach is to determine whether and how the subject system may be susceptible to the characteristics of the PAVE PAWS signal. We consider the PAVE PAWS pulse widths, its apparent pulse repetition frequency (PRF), and its frequency-switching characteristics and then we attempt to determine the PAVE PAWS signal levels at which the subject system will experience noticeable degradation. When these have been

determined, we can estimate the distance from PAVE PAWS at which the degradation will occur.

### D.1.1 Background

Determination of the likelihood of electromagnetic interference (EMI), to some other system, caused by an emitter of electromagnetic fields requires knowledge of the operating characteristics of both systems and of the means by which the electromagnetic energy is propagated from one to the other.

We often speak of the threshold of susceptibility for a system that can be interfered with. It is the lowest level of undesired signal that will cause some perceptible effect on the system (or activity) that may be interfered with; the systems include radar and communication systems, and cardiac pacemakers; activities include the handling of volatile fuels. The threshold of susceptibility typically must be determined separately for each pair of interfering system and potentially interfered-with system. That is because the threshold of susceptibility depends not only on the power density of the undesired signal at the potentially interfered-with system (and therefore on the distance between them); it also depends on the frequency of the undesired signal, on its pulse rate and pulse repetition frequency, and, when applicable, on the strength and frequency of the desired signal. (Examples: TV receivers tuned to channel 10 would show effects that would not occur if tuned to channel 12. A satellite communication system may be susceptible to interference from only a few of the 24 PAVE PAWS channels. A cardiac pacemaker will be insensitive to the difference in the PAVE PAWS frequencies, but will react differently for different pulse rates. A certain radar altimeter is affected the same by all the PAVE PAWS frequencies, but becomes increasingly susceptible for longer, interfering pulse widths.) Further, not all potentially interfered-with systems of the same class (such as land mobile receivers) have the same susceptibility, because of differences in their design.

Theory is useful in predicting likely modes of interference, and it can go far in helping to predict thresholds of susceptibility. However, measurements are often needed -- either when theory is not sufficient, or to confirm the theoretical results. Unfortunately, each new situation is usually unique in one way or another, so that the susceptibility thresholds for that situation are not directly available. For example, inquiry to the persons responsible for EMI in the Electronics Industries Association and to a major U.S. manufacturer of TV receivers reveals that they have no data bearing on the effects of radars such as PAVE PAWS on their products. Table D-1 (taken in part from Donaldson, 1978) shows the variables that must be considered in a test program to define the effect clearly. If each possible test configuration were used, $1.53 \times 10^{10}$ tests would be required, which is clearly

Table D-1

POSSIBLE TEST VARIABLES FOR TELEVISION RECEIVER SUSCEPTIBILITY TESTS

| | |
|---|---|
| 50 | Television sets |
| 82 | Channels |
| 24 | Interference source frequencies |
| 3 | Desired-signal levels |
| 3 | Interference-signal levels |
| 3 | Pulse widths |
| 3 | Pulse repetition frequencies |
| 2 | Effects (audio and video) |
| 4 | Television orientations |
| 5 | Television antennas |
| 2 | Picture scenes |
| 4 | Test configurations |
| | o Television and antenna |
| | o Television alone |
| | o Antenna alone |
| | o Power line |
| 2 | Receiver types (color and monochrome) |
| 3 | Independent viewers |

unrealistic. (This example uses TV receivers, but the nature of the problem would be similar for some other potentially interfered-with system.)

PAVE PAWS generates signals of a highly unusual type, and little information is available to define accurately the susceptibility thresholds of the various systems in its vicinity to its unique type of interfering signal. Some measurement work was done almost 10 years ago on the effects of a phased-array radar, in the same 420-450 MHz band, on some systems, and we use that information to the extent possible (Conklin, 1974). However, that radar's PRF and pulsewidth (and possibly its frequency-hopping) were different, so the results are not directly applicable.

A number of circumstances combine so that definitive statements can seldom be made regarding distances from the radar at which a given system will not be affected. The measured susceptibility levels that are available are generally based on measurements of only a very few units, generally selected in the hope

that they are representative or typical of their type. However, they could be either more or less susceptible than the entire population of units of that type. The variation in the susceptibility levels of all the units of a type may be quite large, but is generally unknown. Also, designs change and so do the susceptibilities. The nature of radio-wave propagation over irregular terrain is such that the interference level will not be the same at a number of locations at the same distance from the source. At a given location, the level varies with time, and so we deal with expected median values. That is also true of the desired signals, when they are applicable.

In some situations, we need not consider actual susceptibility; standards for maximum fields have been established so that the devices or systems are "safe" if that field is not exceeded. Such is the case for electroexplosive devices and for fuel handling.

### D.1.2 Scope

In the analyses that follow in Section D.3, p. D-16, we use combinations of theory and measured data, when applicable, to present those statements that can be made regarding the EMI impact of the PAVE PAWS electromagnetic fields.

## D.2 PAVE PAWS Electromagnetic Fields

### D.2.1 Purpose

The purpose of this section is to explain certain characteristics of the PAVE PAWS signal, specifically the behavior of the signal in time, frequency, and space. This explanation has particular relevance to electromagnetic interference and is supplementary to the description and analysis of Appendix A.

### D.2.2 Basic Radar Operation

A radar operates by transmitting a pulse of electromagnetic energy and then waiting to receive energy reflected back to the radar from a target hit by the original pulse. The radar interprets the time interval between the transmitted pulse and the return as a measure of the distance from the radar to the target.

It is highly advantageous, for several reasons, for the radar to concentrate its transmitted energy (and to limit its receiving capability) in a relatively narrow beam. A narrower beam permits greater certainty regarding the direction in which the energy was sent and from which it returned, thus better defining the direction from the radar to the target. A narrower beam not only

conserves the available energy (because it concentrates it into a single direction), it can also receive weaker returns from a particular direction while discriminating against electromagnetic noise or extraneous, interfering signals that may arrive from other directions.

Radars have long used parabola-shaped reflectors -- or dishes -- to form beams in the same manner that the silvered reflector of an automobile headlight forms a beam from the light emanating from the lamp's filament. In both cases, the radiating element is often hardly noticeable in front of the reflecting dish. To move the beam, the radar dish (and the radiating element) are typically rotated at a particular fixed rate to sweep past a given azimuth every second or so.

### D.2.3 PAVE PAWS Beam

#### D.2.3.1 General

PAVE PAWS differs from a conventional radar in several respects. Each of its two faces is covered with a large number of small fixed radiating elements, each of which is driven by its own transmitter under the control of a computer. The computer can adjust the phase of the transmitted (and received) energy of each radiating element relative to that of the others to form a very narrow beam of energy. Each complete antenna face is known as a phased array. Because it has no moving mechanical parts, the phased array can switch its beam from one part of the sky to another within a few microseconds, unhampered by mechanical inertia. Thus, instead of sweeping, the PAVE PAWS beam can be thought of as probing from any given direction to any other within its limits. Each of the two faces of the PAVE PAWS radar covers an azimuthal sector 120 deg wide. Together they can make observations in a 240 deg sector from 347 deg (i.e., 13 deg west of north) to 227 deg (i.e., 47 deg west of south).

#### D.2.3.2 Beam Structure

Each of the two faces of PAVE PAWS forms a single main beam with associated sidelobes, as indicated in Table A-1, p. A-3. The sidelobes result from the inability of the radar to concentrate absolutely all of the energy in the main beam. The location and level of the first sidelobe are fairly well known. The higher order (and very minor) sidelobes are distributed at various, almost random, angles. They have power densities no greater than 0.001 that of the main beam, and some are as small as 0.00003 of the power density of the main beam. There are a large number of these minor sidelobes, and their average level in the basic system is about 0.00016 that of the main beam power density (0.00008 for the growth system).

D.2.3.3 Beam Motion

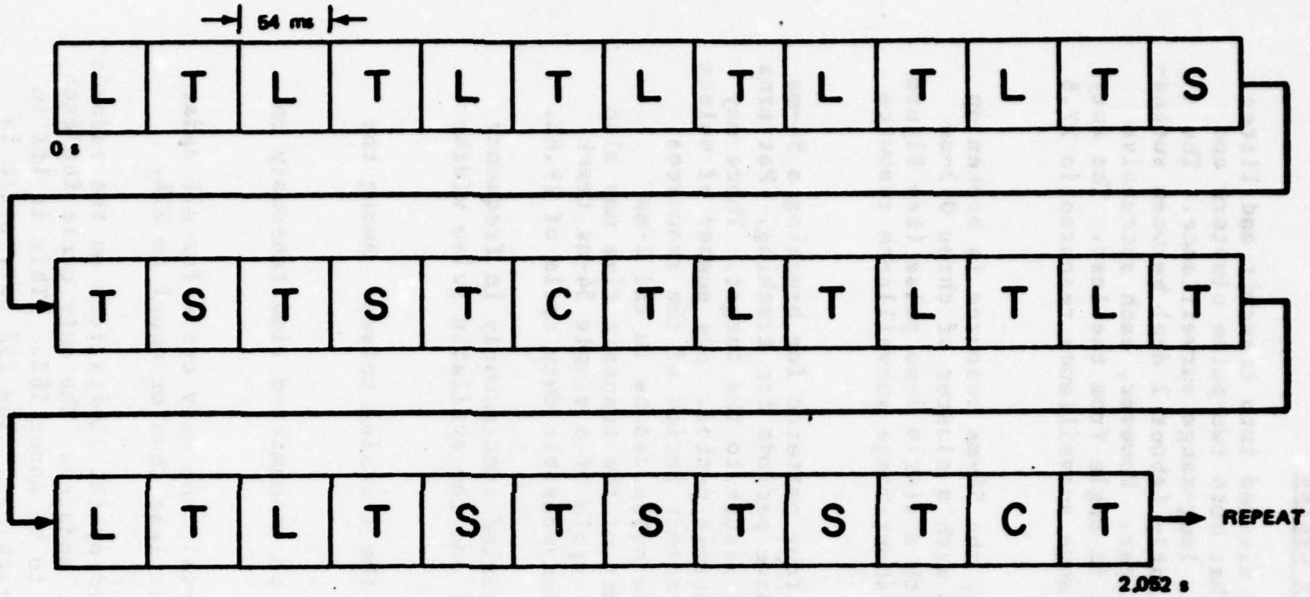
PAVE PAWS is used both for surveillance and for tracking space objects. Operating time is broken into 54-ms intervals called resources. Successive resources can be used for surveillance, for tracking, or for calibration and monitoring of performance and interference. Time is shared between the various functions of the radar. A nominal template (an arrangement of 54-ms resources) is shown in Figure D-1. The pattern repeats every 38 x 54 ms = 2.052 s. Fifty percent of the resources are used for tracking, 44.7% for surveillance, and 5.3% for calibration and monitoring of performance and interference.

During reduced surveillance, only about one out of four resources is devoted to surveillance; the others are used for tracking. During enhanced surveillance, more than half of the resources are used for surveillance.

D.2.3.3.1 Long-Range Surveillance. Both faces of the radar search simultaneously and their beams operate in synchronism. The beam normally remains at a 3 deg elevation angle, but can be moved up to 10 deg in increments for operational reasons. The beam is switched from one azimuth to another in a complicated but fixed manner during a scan sequence, hitting each spot in the 120 deg sector about 7 to 24 times. (The spots toward the edges of the sector are hit more often than those toward the center.) In normal operation, the sequence takes 43.97 seconds, and then it repeats itself. (During this time, the radar is also performing its short-range surveillance and its tracking activities.) In enhanced or reduced surveillance, the sequence takes a shorter or a longer time, but the same spots are still hit in the same order.

D.2.3.3.2 Short-Range Surveillance. In this mode, the beam's elevation angle is the same as it was for long-range surveillance, and both faces continue to search simultaneously and in synchronism. At a normal surveillance rate (see Figure D-1), the beam takes about 9.22 seconds to hit each part of the 120 deg sector the 4 or 5 times required for short-range surveillance.

D.2.3.3.3 Tracking. The two faces track independently, according to the number and locations of objects needing to be tracked. The beam is limited to a minimum elevation angle of 3 deg and a maximum of 85 deg. Tracking is time-shared with the radar's surveillance functions; when fewer objects must be tracked, more of the resources are available for surveillance. Tracking pulses are never sent simultaneously from both faces.




L - LONG-RANGE SURVEILLANCE

S - SHORT-RANGE SURVEILLANCE

T - TRACK OR VERIFICATION

C - CALIBRATION AND PERFORMANCE MONITORING (EVERY 18th OR 20th RESOURCE, ALTERNATELY)

FIGURE D-1. NOMINAL RADAR RESOURCE TEMPLATE

## D.2.4 PAVE PAWS Pulses and Duty Cycles

The 54-ms radar resource is divided into transmit and listen periods. Figure D-2(a) shows that both two-pulse clusters and three-pulse clusters are used in long-range surveillance. The beam position is moved only slightly (about 2 deg) between successive pulses of a particular cluster. However, each successive cluster may be widely separated in angle from the last. The duty cycle for a single 54-ms long-range surveillance resource is 27.8 to 29.6%.

In short-range surveillance, the 54-ms resource is broken up into three 12-ms sections, each with a cluster of three 0.3-ms pulses, and an 18-ms segment with a single 3-ms pulse (see Figure D-2(b)). The duty cycle for a short-range surveillance resource is about 1.1%.

Figure D-3, p. D-10, shows four patterns for breaking a 54-ms resource into transmit and receive periods for tracking. Patterns are selected according to the distance to the target. There may be more than one pulse in a transmit period. Any number of pulses up to eight can occur in the transmit period of the resources labeled $T_1$, $T_2$, and $T_3$; only one pulse can be in the 2-ms transmit periods of $T_4$. Any part of the transmit time may also be empty; this reduces the duty cycle of a single 54-ms track resource to less than its maximum-possible duty cycle of 29.6%.

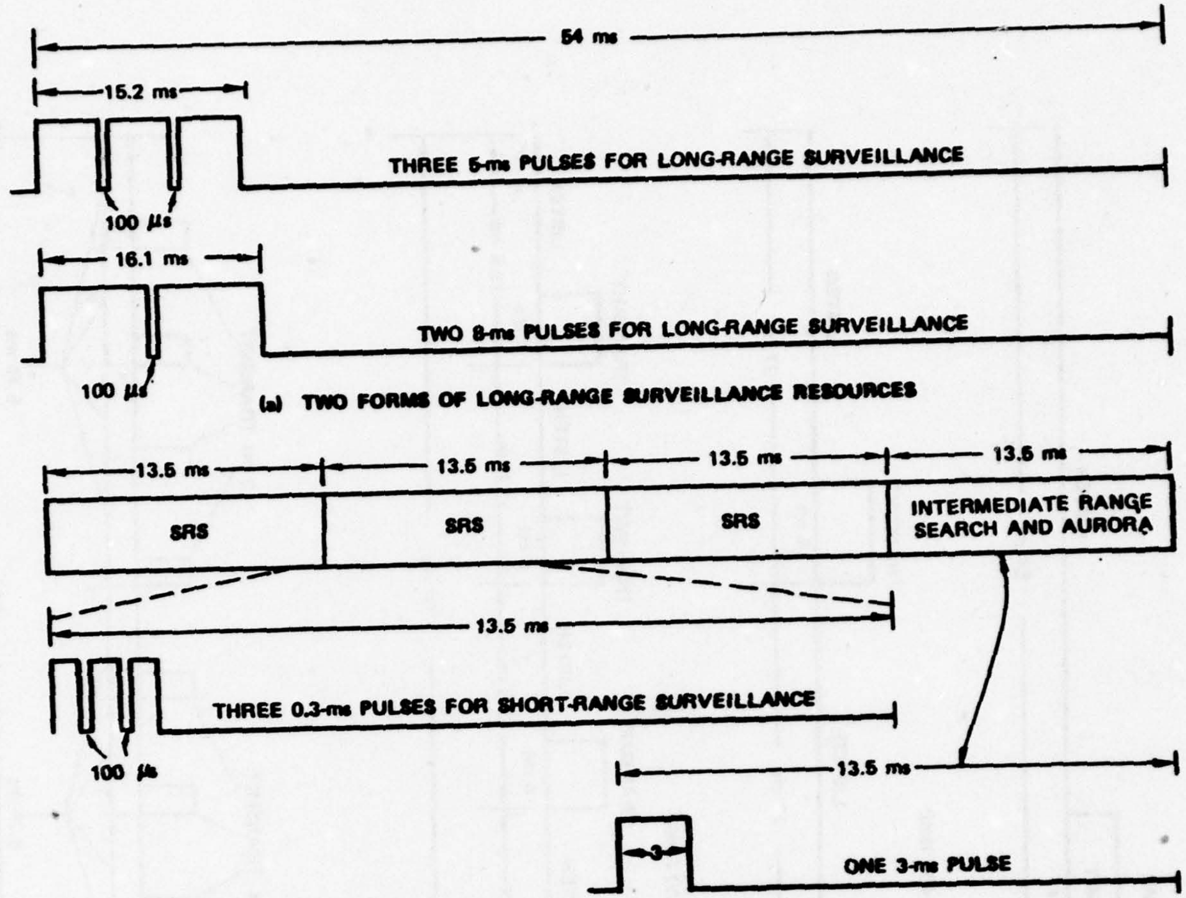
Track pulses are chirped (varied continuously in frequency over a frequency band of 1 MHz) and the available pulse widths range from 16 to 0.25 ms.

Various algorithms dictate the tracking pulses. Among the constraints are:

- Track pulses must not be transmitted simultaneously on both faces.

- For any 1-second interval, the duty cycle for all radar activities on a face is less than or equal to 25%.

The latter constraint is imposed by the limitations on the radar's ability to cool the transmitter modules. The duty cycle for each face is expected almost always to be about 18%. (This is 11% in surveillance and the rest in tracking.) The 25% duty cycle is expected to occur only under the most stressful circumstances (for example, during a missile attack), when one face would be used heavily for tracking targets. If this were to occur, the duty cycle for the other face would have to be reduced to about 11% to avoid exceeding the system's ability to cool the transmitter modules.




(a) TWO FORMS OF LONG-RANGE SURVEILLANCE RESOURCES

(b) THE BREAKDOWN OF A SHORT-RANGE SURVIELLANCE RESOURCE (SRS)

FIGURE D-2. LONG-RANGE AND SHORT-RANGE SURVEILLANCE RESOURCES ++

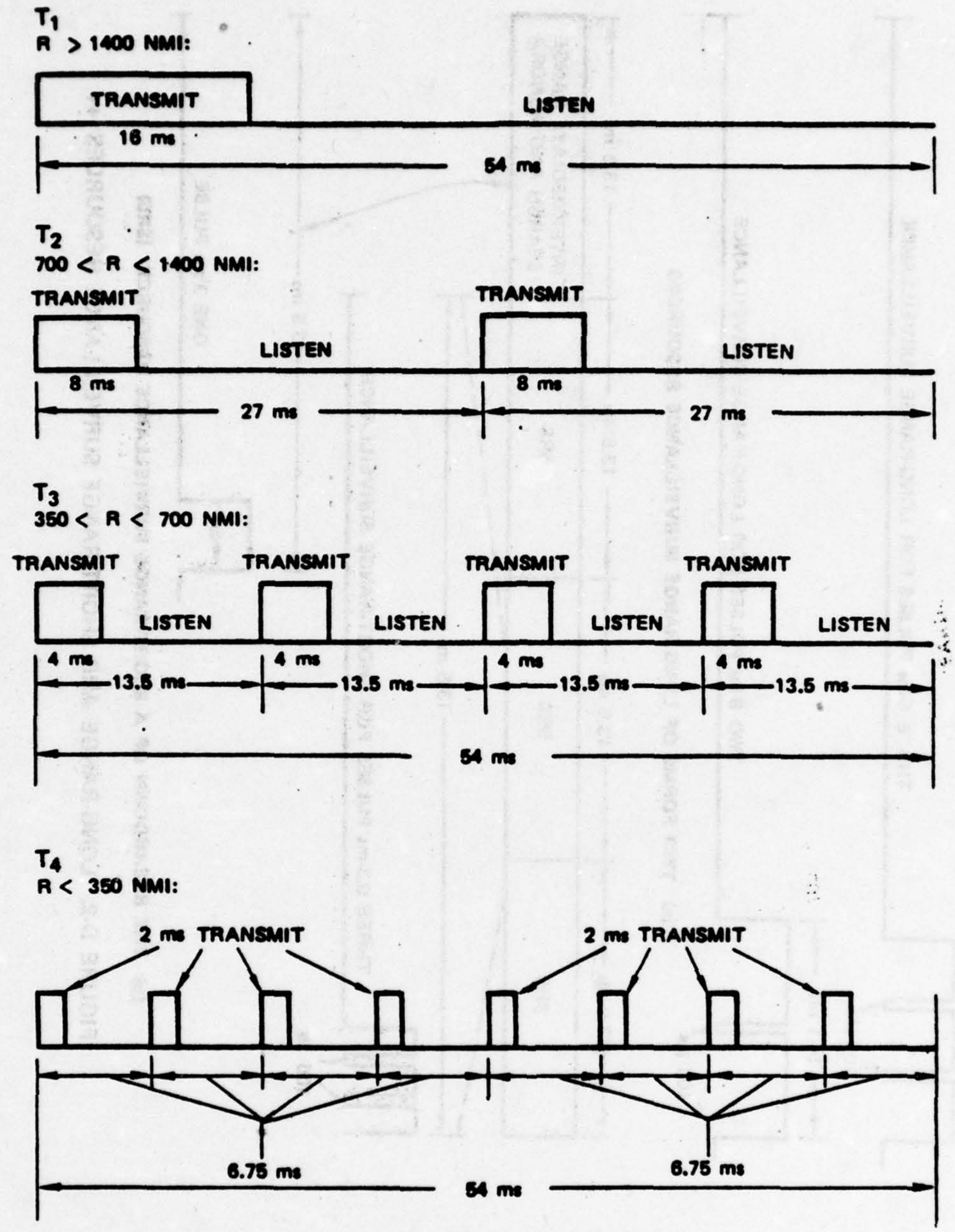



FIGURE D-3. TRACK RESOURCES

### D.2.5 PAVE PAWS Frequency Switching

The PAVE PAWS radar transmits on the 24 channels illustrated in Table D-2, generally switching frequency between one pulse and the next. Although the pulses of the two- or three-pulse clusters of the long-range surveillance resources differ in frequency by only about 200 kHz, every other surveillance or tracking pulse is shifted at least 3.6 MHz from the preceding pulse. A different frequency is used for each short-range search pulse in the same resource and also for each tracking pulse in the same resource. Also, no frequency can be used in a long-range surveillance resource that has been used in the immediately preceding track resource.

The 24 center frequencies, spaced at 1.2-MHz intervals from 420 to 450 MHz, are interleaved in three sets of eight, as illustrated in Table D-2. The radar selects increasingly higher frequencies from set A, recycling through the set A frequencies for about 31 resources (approximately 1.67 seconds). The radar then proceeds similarly with the set B frequencies, and then the set C frequencies. Thus, the normal jump from one pulse to the next is 3 x 1.2 MHz = 3.6 MHz. (The frequency shift is less within the pulse cluster of the long-range surveillance resource mode and greater when the radar jumps from one frequency set to the next.) It takes about 2.56 seconds for a signal to propagate to the moon and back, and the result of using the three frequency sets sequentially is that the radar's receiving system is tuned for frequencies from sets B and C when the moon echoes of the set A frequencies are finally returned to earth. The same holds true, of course, for the other two frequency sets so that the radar is never confused by a moon echo.

The radar operator can choose to delete any of the possible frequencies from those available for use. Frequencies are also deleted automatically if an auxiliary receiver detects undue interference on any of them. Thus, PAVE PAWS switches from one frequency to another at least every 54 ms; the exact frequency usage cannot be predicted because it depends on the number and the locations of the objects being tracked.

### D.2.6 The Received PAVE PAWS Signal

#### D.2.6.1 Illumination of an Airborne Object

An aircraft or other object flying in the 240 deg sector covered by PAVE PAWS would be illuminated by the surveillance-mode main beam when it is in the shaded region indicated in Figure D-4, p. D-13. This raises the possibility that PAVE PAWS could affect airborne systems. This possibility will be discussed in Section D.3.1.5, p. D-56.

Table D-2

PAVE PAWS FREQUENCIES

| Channel Number | Center Frequency (MHz) | Frequency Set |
|---|---|---|
| 1 | 421.3 | A |
| 2 | 422.5 | B |
| 3 | 423.7 | C |
| 4 | 424.9 | A |
| 5 | 426.1 | B |
| 6 | 427.3 | C |
| 7 | 428.5 | A |
| 8 | 429.6 | B |
| 9 | 430.8 | C |
| 10 | 432.0 | A |
| 11 | 433.2 | B |
| 12 | 434.4 | C |
| 13 | 435.6 | A |
| 14 | 436.8 | B |
| 15 | 438.0 | C |
| 16 | 439.2 | A |
| 17 | 440.4 | B |
| 18 | 441.5 | C |
| 19 | 442.7 | A |
| 20 | 443.9 | B |
| 21 | 445.1 | C |
| 22 | 446.3 | A |
| 23 | 447.5 | B |
| 24 | 448.7 | C |

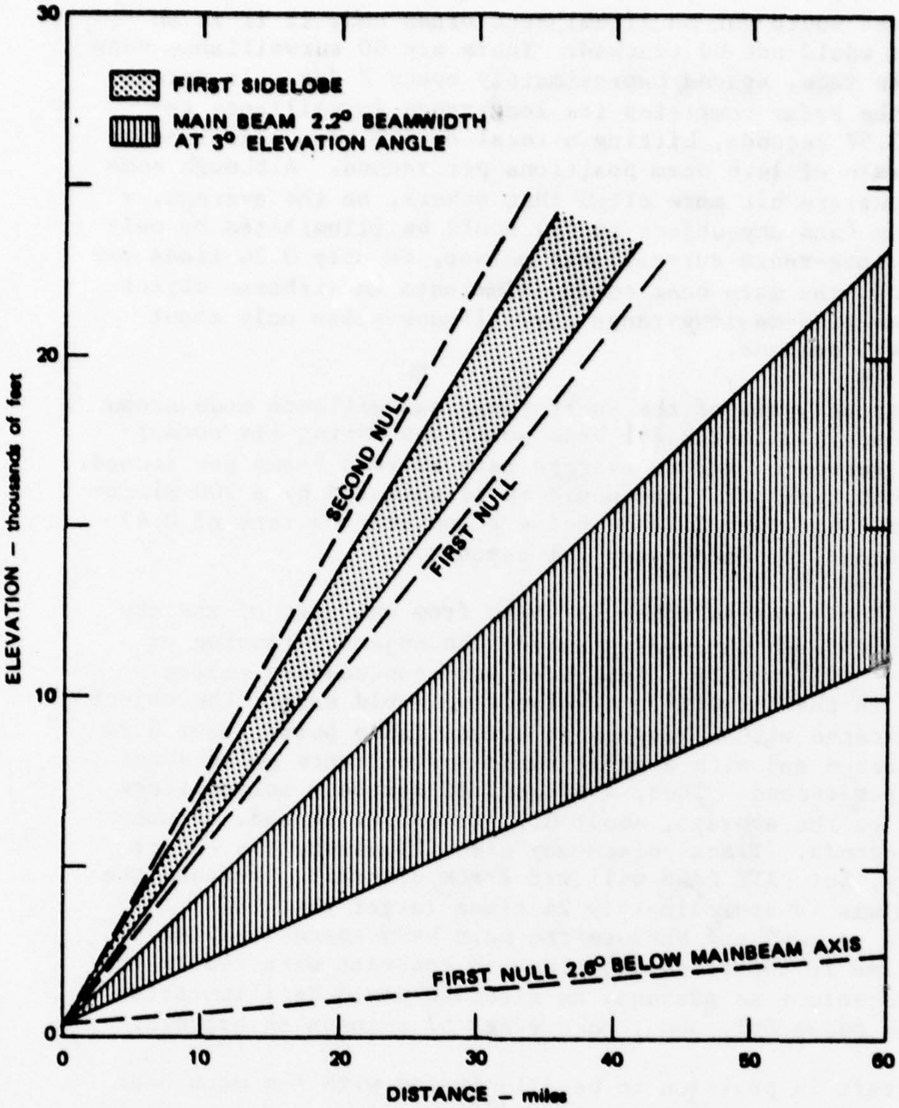



**FIGURE D-4. VERTICAL PLANE CUT OF PAVE PAWS BEAM IN SURVEILLANCE MODE, BASIC SYSTEM**

The object would not be illuminated often and, if it is an aircraft, it would not be tracked. There are 60 surveillance beam positions per face, spaced approximately every 2 deg. In normal operation, the radar completes its long-range surveillance sequence in 43.97 seconds, hitting a total of 642 beam positions at an average rate of 14.6 beam positions per second. Although some beam positions are hit more often than others, on the average, a beam position (and any object in it) would be illuminated by only 1/60 of the long-range surveillance pulses, or only 0.24 times per second. Thus, the main beam could illuminate an airborne object with the 5-ms or 8-ms long-range surveillance pulse only about once every 4.1 seconds.

A similar analysis of the short-range surveillance mode shows that the radar illuminates 261 beam positions during its normal 9.22-second sequence, for an average rate of 28.3 beams per second. Each of the 60 beam positions would be illuminated by a 300 microsecond short-range surveillance pulse at an average rate of 0.47 times per second, or once every 2.1 seconds.

Because the radar switches the beam from one part of the sky to another with each succeeding pulse, the object -- moving or stationary -- will not be illuminated with consecutive pulses. While it is in the surveillance volume, we would expect the object to be illuminated with a long-range surveillance pulse about 0.24 times per second and with a short-range surveillance pulse about 0.47 times per second. Thus, some sort of mainbeam surveillance pulse hits, on the average, about 0.71 times per second, or once every 1.4 seconds. Track pulses may also illuminate the object occasionally, but PAVE PAWS will not track aircraft. Because the tracking volume is approximately 26 times larger than the surveillance volume, and because the main beam spends only about 7% of the time in the tracking volume in contrast with 11% in the surveillance volume on average, an aircraft would be illuminated with a track pulse only about once every 57 seconds on average.

An aircraft in position to be illuminated with the main beam would also be illuminated by energy from the first sidelobe (with a power density 0.01 (20 dB less than) that of the main beam power density) and by the minor sidelobes (with power density averaging about 0.00016 (38 dB less than) that of the main beam). First-sidelobe energy would illuminate the aircraft only when the surveillance mode main beam is directly to either side of the aircraft or when a track beam is very close. These first-sidelobe pulses would therefore hit the craft about twice as often as main-beam pulses do. Minor-sidelobe energy would illuminate the aircraft during each transmitter pulse for which the aircraft is not illuminated by the main beam or by the first sidelobe. Even when the aircraft is not within the main-beam volume, it could be illuminated by the first and higher-order sidelobes, as is indicated in Figure D-4.

#### D.2.6.2 Illumination of a Ground-Based Object

Main-beam energy does not impinge on the earth. First-sidelobe energy of the basic system does so in some areas, but objects on or near the earth's surface are generally illuminated only by the radar's higher-order sidelobes (that is, those beyond the first). The higher-order sidelobes are located at angles greater than about 4 deg from the main beam. From this it follows that a nearby object is likely to be illuminated by one of the higher-order sidelobes regardless of the direction of the main beam, and that the object will be illuminated during each of the radar's pulses.

PAVE PAWS does not have a specific pulse repetition frequency (PRF), as do most radars. This is because it adapts its operation to the targets being tracked. The number of pulses per second can be estimated, but this will not be a PRF in the usual sense. Each second, an average of 14.6 long-range surveillance pulses and 28.3 short-range surveillance pulses are emitted. During that same second, about 40% of the 18.5 resources are used for tracking -- with unpredictable pulse formats. An estimate of an average of 4 pulses per tracking resource leads to about 30 tracking pulses per second. Thus, there will be about 73 pulses of some kind per second. These are of various widths and have various interpulse intervals.

Now consider the duration the object is illuminated. Of the 14.6 long-range surveillance pulses emitted each second, each pulse is either 5 ms or 8 ms long. The 8-ms pulses are used at angles greater than 45 deg off the boresight. An average of 28.3 300-microsecond short-range surveillance pulses are also emitted each second. If we assume that half of the long-range surveillance pulses are 8 ms long and half are 5 ms long, and if we add them and the short-range pulses, we find that an object is illuminated by surveillance pulses for about 104 ms per second, or about 10.4% of the time. For up to about another 7% of the time it may also be illuminated by track pulses.

An object in some locations could also be illuminated by the PAVE PAWS first sidelobe as the surveillance-mode main beam passes over it. Such hits would occur at least once every 1.4 seconds. (If the location can be illuminated by the sidelobe in two beam positions, the rate doubles, and so on.) The first sidelobe is closer to the main beam in the growth system than it is in the basic system. Therefore, some areas may be illuminated by first-sidelobe power only in the basic system.

#### D.2.6.3 Pulse Power Density

At distances greater than about 1,500 feet and in the main beam, the power density of a PAVE PAWS pulse in the basic system is

(from the far-field equation of p. A-15)

$$P_r = 50.5 - 20 \log d \quad dBm/m^2$$

for d miles. (The dimension $dBm/m^2$ means decibels relative to 1 milliwatt per square meter.) The pulse power density of the first sidelobe is 20 dB less than that of the main beam:

$$P_r = 30.5 - 20 \log d \quad dBm/m^2$$

The maximum value for the higher-order sidelobes is about 30 dB lower than that of the main beam, so illumination by those sidelobes has a power density of

$$P_r = 20.5 - 20 \log d \quad dBm/m^2.$$

The rms value of the high-order sidelobes for the basic system is about 38 dB less than that of the main beam, so the average pulse power density from high-order sidelobes is

$$P_r = 12.5 - 20 \log d \quad dBm/m^2.$$

The figures derived by these equations apply in line-of-sight situations. In other situations, the power density will be much less. For areas that are shadowed by terrain, a conservative estimate would be that the power density is at most 1/10th as great (at least 10 dB lower). Longley (1978) summarized the literature on attenuation of signals by trees. The effect will be highly variable, depending on the height of the receiving antenna and its location relative to PAVE PAWS. An additional power loss of about 10 dB is a reasonable expectation for a PAVE PAWS signal that has passed through a few hundred meters of the thick forest in the area of Otis AFB.

In the growth system, the transmitter power is doubled and the antenna gain is doubled, so the main-beam received power and the first-sidelobe received power are increased by a factor of 4 (6 dB). However, the rms value of the high-order-sidelobe gain becomes 41 dB less than the main-beam gain (as opposed to 38 dB for the basic system) so that the power density of the higher-order sidelobes is only doubled (increased by 3 dB).

## D.3 PAVE PAWS Effects on Systems

### D.3.1 Telecommunications Systems

#### D.3.1.1 Effects on Amateur Radio -- A Secondary Service

Besides sharing the 420 to 450 MHz band with other radars, PAVE PAWS shares it with the Amateur Radio Service. The FCC con-

siders the Amateur Radio Service to be a secondary service in the band; its primary service is radiolocation (i.e., radars). Secondary services do not enjoy the privileges of primary services. The following, quoted from Vol. II, Section 2.105, of the FCC's Rules and Regulations, defines the rights of each. +

> Note 1. Geneva Radio Regulation No. 138: Permitted and primary services have equal rights, except that, in the preparation of frequency plans, the primary services, as compared with the permitted services, shall have prior choice of frequencies.
>
> Note 2: Geneva Radio Regulation No. 139: Stations of a secondary service: (a) Shall not cause harmful interference to stations of primary or permitted services to which frequencies are already assigned or to which frequencies may be assigned at a later date; (b) cannot claim protection from harmful interference from stations of a primary or permitted service to which frequencies are already assigned or may be assigned at a later date; (c) can claim protection, however, from harmful interference from stations of the same or other secondary service(s) to which frequencies may be assigned at a later date.

The amateurs operate a number of FM repeaters (relays) in the band between 442 and 450 MHz to permit communication over greater distances than would otherwise be possible. The ARRL Repeater Directory (1978-79), including all repeaters that were registered + with the ARRL up to 1 March 1978, lists 18 such repeaters in + Massachusetts. The closest in the ARRL list is at Fall River, about 30 miles west of (and behind) PAVE PAWS. It receives on 444.35 MHz and transmits on 449.35 MHz. Another, in Somerset near + Fall River, receives on 448.65 MHz and transmits on 443.65 MHz. +

A small number of amateurs are engaged in weak-signal experimentation in the band 432.0-432.1 MHz. About 100 amateur stations communicate by moon-bounce (Baldwin, 1978). That is, they propagate signals to other stations by reflecting them off the moon, using antennas with gains in the vicinity of 24 dBi. Thus, assuming a 1-kw (60 dBm) transmitter power, their effective radiated power is about 84 dBm. The effective radiated power of the higher-order sidelobes for the PAVE PAWS basic system is about 88 dBm (2.5 times as great as the amateurs' signals). Thus we can expect that an amateur moon-bounce link could receive moon-bounce interference from PAVE PAWS when the moon is visible to both of the amateur stations involved and to a face of PAVE PAWS. Because of PAVE PAWS frequency-hopping, the moon-bounce experimenters would receive 1/24th of the PAVE PAWS pulses. The PAVE PAWS main beam is never directed toward the moon.

The amateurs are authorized to use satellite transponders in the band 435 to 438 MHz. Currently, two amateur satellites are in orbit, OSCAR 7 and OSCAR 8 (Orbiting Satellite Carrying Amateur Radio); both are in near-polar orbit. Table D-3 presents some information on their orbits and frequencies (Kleinman, 1978; Harris, 1978; Glassmeyer, 1978). Both OSCARs transmit information on the condition of the satellite's battery and other subjects. Each has two linear transponders that accept single-sideband voice or CW (code) signals in one band and retransmit them in another.

Table D-3

SOME PARAMETERS OF CURRENTLY ORBITING AMATEUR SATELLITES

| | OSCAR 7 | OSCAR 8 |
|---|---|---|
| Orbit period | 115 min | 103 min |
| Orbits per day | 12.5 | 14.0 |
| Maximum time per orbit within view of PAVE PAWS | 22 min | 17 min |
| Altitude | 1,500 km | 900 km |
| Inclination[a] | 102 deg | 99 deg |
| Frequencies (MHz) | | |
| "Mode A" | | |
| Uplink | 145.88-145.95 | 145.85-145.95 |
| Downlink | 29.4-29.5 | 29.4-29.5 |
| "Mode B" | | |
| Uplink | 432.125-432.175 | - |
| Downlink | 145 | - |
| "Mode J" | | |
| Uplink | - | 145.9-146.0 |
| Downlink | - | 435.1-435.2 |
| Telemetry Beacons | 29.502, 145.972 | 29.402, 435.095 |

[a]Inclination is the angle between the orbit's track and the equator. Zero degrees describes an equatorial orbit, with the satellite moving east; 90 deg is a polar orbit. Angles greater than 90 deg imply that the satellite moves west.

OSCAR 7's "Mode B" transponder receives within the PAVE PAWS band and OSCAR 8's "Mode J" transponder transmits within that band. According to QST, "the Mode J transponder is expected to be operational during weekends, although not continuously." More recent information is that operation now averages 72 hours per week.

OSCAR 7 and OSCAR 8 orbit the earth 12.5 and 14.0 times per day, respectively. As they pass directly over PAVE PAWS, OSCAR 7 will be in the line of sight of the radar for 22 minutes and OSCAR 8 for 17 minutes. Of course, these line-of-sight times are for passes directly overhead; the time will be less for all other satellite passes. When they are within the line of sight, the satellites are illuminated by the radar in the same way as for the aircraft discussed in Section D.2.6.1, p. D-14, are illuminated. Radar energy reflected from the moon could also illuminate the satellites as well as the amateur ground stations.

No analysis of the susceptibility of the OSCAR satellites and the ground receivers to the PAVE PAWS is included here, although the amateurs themselves are said to be "carefully studying the problem" (Ham Radio Magazine, August 1978). As yet, the OSCAR satellites are not heavily used, partly because the required equipment (particularly for receiving OSCAR 8's 435-MHz downlink) is not widely available (Kleinman, 1978). Another satellite is planned for launch early in 1980.

It may be possible, because the satellites' orbits are known, to program PAVE PAWS frequency usage (consistent with operational requirements) so that the PAVE PAWS frequencies that would interfere with a satellite's transponder would not be used during the periods that the satellite is visible. It may also be possible, when operational requirements permit, to avoid use of the 432-MHz frequency when the moon is visible, to avoid interference to moonbounce communications.

### D.3.1.2 Interference to Television

Several of the VHF TV channels between 4 and 12 and UHF channels 27, 38, and 56 are used in the vicinity of PAVE PAWS. Table D-4 lists them and shows the frequency bands they occupy. Degradation to TV reception from signals far in frequency from the TV bands has been studied (Coklin, 1974).

Degradation to TV reception is said to occur when an observer can detect the presence of the interfering signal. For television reception, interference to the video portion generally occurs first. That is, the video effect is usually perceptible at lower interfering-signal levels than are required for a perceptible audio effect.

Table D-4

TV CHANNELS IN USE IN THE VICINITY OF PAVE PAWS

| TV Channel | Band (MHz) | Video Carrier Frequency (MHz) | Local Oscillator Frequency ($f_{LO}$) (MHz) | Delta f[a] (MHz) |
|---|---|---|---|---|
| 4 | 66-72 | 67.25 | 113 | 353 to 383 |
| 5 | 76-82 | 77.25 | 123 | 343 to 373 |
| 6 | 82-88 | 83.25 | 129 | 338 to 368 |
| 7 | 174-180 | 175.25 | 221 | 245 to 275 |
| 10 | 192-198 | 193.25 | 239 | 227 to 257 |
| 12 | 204-210 | 205.25 | 251 | 215 to 245 |
| 27 | 548-554 | 549.25 | 595 | -39 to -9 |
| 38 | 614-620 | 615.25 | 661 | -195 to -165 |
| 56 | 722-728 | 723.25 | 769 | -303 to -273 |

[a]Delta f = PAVE PAWS frequency (420 to 450 MHz) minus TV video carrier frequency.

There have been only very limited tests using real and simulated PAVE PAWS signals to determine their ability to interfere with TV reception. MITRE has experimented with simulated PAVE PAWS signals, using 3 monochrome TV receivers and 1 color TV receiver, and they have also operated a small portable battery-operated black-and-white TV receiver in the vicinity of PAVE PAWS (MITRE, 1978). Their work with the simulated signals corroborates other results described here. They were able to operate that particular portable set within 3,400 ft of PAVE PAWS (and possibly shielded by vegetation) without noticeable degradation to the Channel-10 signal. They have also observed TV reception at two motels in Sandwich (both shielded by terrain and foliage) and could see no interference. This small sample of directly applicable data (with the appropriate frequency, pulse width, and PRF) strengthens confidence in the conclusions that were reached before that test data was available.

### D.3.1.2.1 Saturation Responses

Tests by Conklin (1974) suggest that strong signals in the PAVE PAWS frequency band can affect TV reception. It seems that the pulse width does not make much difference in the interference threshold. Conklin describes the appearance of (nonsaturating) pulsed interference as dashes appearing at the beginning and at the end of the pulse, saying that "nothing is visible during the remaining period that the pulse is on, since the steady-state portion is regarded by the receiver the same as a CW signal is." Thus a nonsaturating pulse provides two groups of dashes at widely separated parts of the TV screen. If the interfering signal is strong enough to saturate the TV receiver, the pulse width is important, however, because the pulse wipes out the picture for an instant between the two groups of dashes.

For reasons having to do with the PAVE PAWS pulse repetition frequency, and the frequency offset from the TV channels, strong PAVE PAWS signals could saturate a TV receiver. Conklin says that the saturation response level is relatively insensitive to the level of the TV signal itself and that saturation will occur at an interference power level at the receiver of approximately 12 mW (+11 dBm). No information was given on how many TV sets were examined to obtain that number or how many viewers were used as subjects.

### D.3.1.2.2 Spurious Responses

A receiver can accept and process signals at frequencies far from the one to which it is tuned. Such an action is called a spurious response and the interfering frequency that produces it is called a spurious response frequency. Spurious response frequencies, $f_{sp}$, are found by solving the equation:

$$f_{sp} = \mathrm{abs}\left(\frac{pf_{LO} \pm f_{IF}}{q}\right)$$

where $f_{LO}$ = the receiver's local oscillator frequency

$f_{IF}$ = the receiver's intermediate frequency

p,q = integers denoting the harmonics, respectively, of the local oscillator and the interfering frequency,

and abs indicates the absolute value of the expression. PAVE PAWS frequencies can cause spurious responses in TV receivers. The TV receiver passband extends from 41 to 47 MHz. When we set p = 2, q = 1, we are in effect searching for strong external signals that can mix with the second harmonic of the local oscillator so that the difference frequency falls within the IF passband and is amplified as if it were part of the desired TV signal. Figure D-5

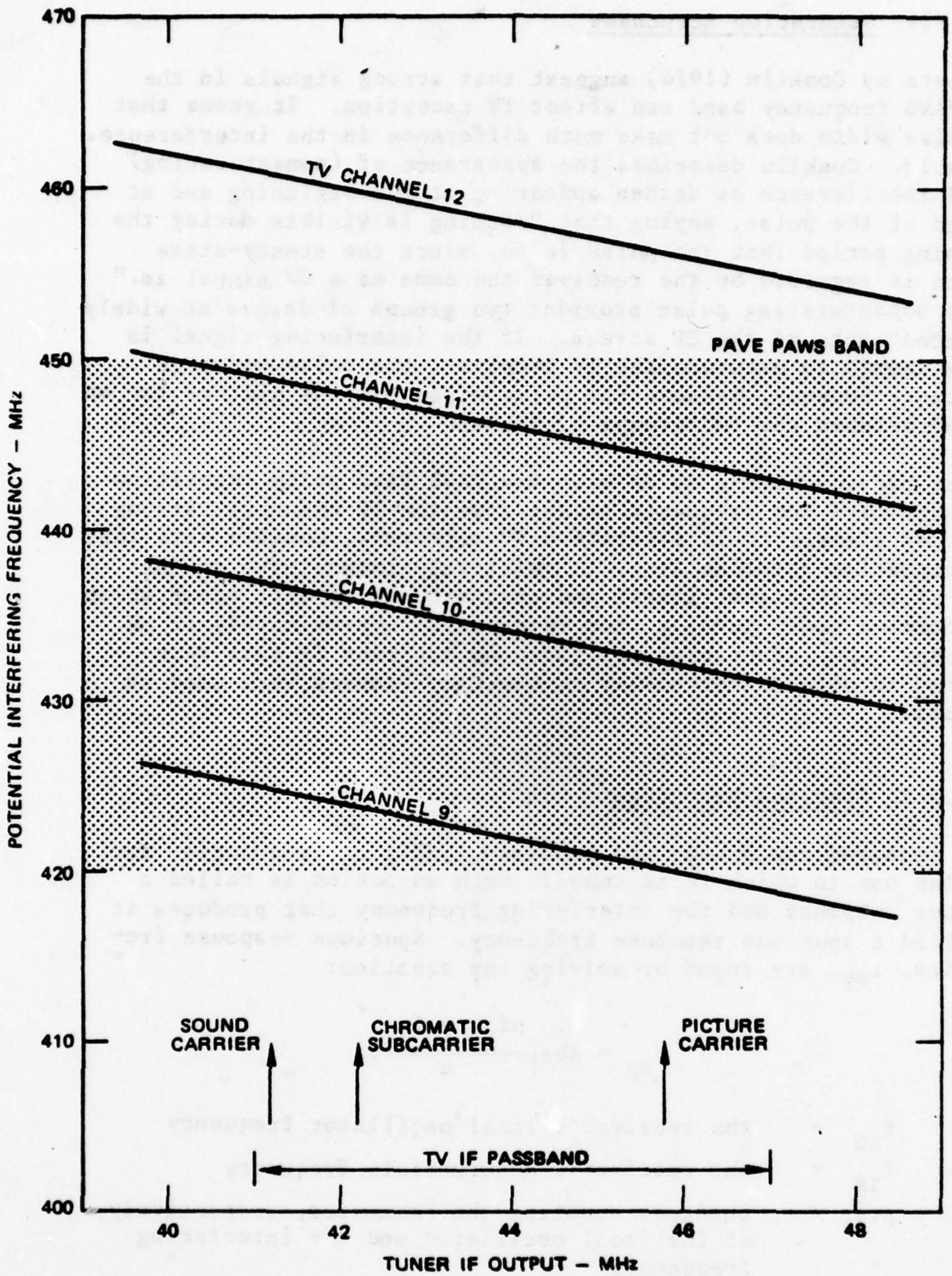



FIGURE D-5. TELEVISION RECEIVER SPURIOUS–RESPONSE FREQUENCIES IN AND NEAR THE PAVE PAWS BAND (p = 2, q = 1)

shows that VHF channels 9 through 11 are potentially susceptible to spurious responses of the p = 2, q = 1 type caused by PAVE PAWS. Higher-order spurious responses in the VHF TV band may also occur, but only when the levels of the interfering signal are much higher. Channel 10 will be of concern because it is used in the PAVE PAWS area, whereas channels 9 and 11 are not. Spurious responses occur in UHF TV channels 60 through 83 for p = 1, q = 2, but these TV channels are not in use in the vicinity of PAVE PAWS.

The Channel-10 spurious response of 12 color TV receivers were measured; the results, shown in Figure D-6, show that there is a large range in the susceptibility of various TV receivers. The interfering signal had pulse widths of 100 microseconds, 200 microseconds, and 1,000 microseconds, with a PRF of 40 pps. Although the frequencies involved are the same as those of PAVE PAWS, this information does not permit us to predict whether higher or lower thresholds of susceptibility would result from using the actual PAVE PAWS signal, with its generally longer pulse and unusual "PRF." The measurements represented by Figure D-6 were made at a TV signal level of -77 dBm at the TV receiver terminals. Figure D-7, p. D-25, shows how the pulse interference threshold increases as TV signal strengths increase.

D.3.1.2.3 <u>High Power Effects</u>. High power effects result when a strong signal couples power directly into a system's internal circuitry and components. Measurement programs have been done to determine thresholds for high-power effects for TV receivers. The PRF and pulse widths of a radar system somewhat similar to PAVE PAWS were used. In one program, five monochrome and two color sets, all made in or before 1967, were used. Mean power density thresholds of about 30 dBm/m$^2$ (100 microwatts/cm$^2$) were found, which are independent of the level of the desired TV signal. Use of a preamplifier with the TV antenna resulted in threshold susceptibility levels about 10 dB lower. Some of these data have recently become more widely available (Donaldson, 1978).

In another program, 45 TV receivers (1970 models, 15 monochrome and 30 color) were used. At the PAVE PAWS frequency the mean susceptibility threshold was about 24 dBm/m$^2$. This work was done at a PRF of 300 pps with a pulse width of 10 microseconds; PAVE PAWS signals may be less disruptive. The data included here as Table D-5, p. D-26, were reported, and although the measurement conditions used to obtain these data were not specified, the frequency band (420 to 450 MHz) is appropriate. It did say that for TV channels below 10, most of the degradation results from antenna-coupled interference. Thus, the power densities in Table D-5 can be converted to power levels at the TV receiver by multiplying by the TV antenna's effective aperture and accounting for some loss in the antenna feedline. The effective receiving area of an antenna is directly proportional to its gain. (See p. 25-8 of Reference Data for Radio Engineers.) If TV

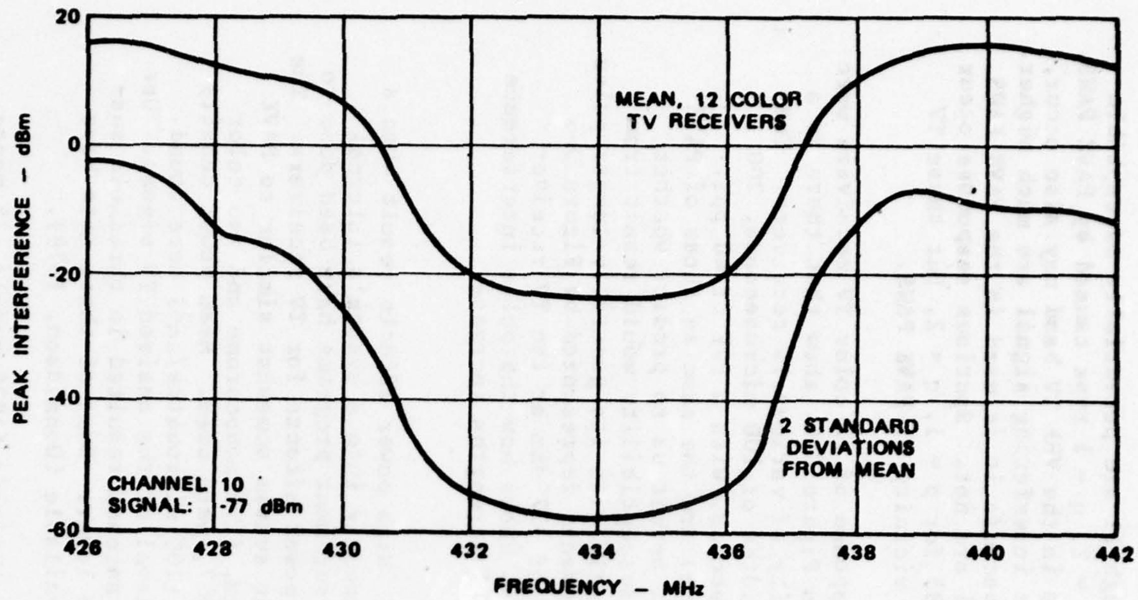



FIGURE D-6. TV CHANNEL-10 INTERFERENCE THRESHOLD FOR p = 2, q = 1 SPURIOUS RESPONSE

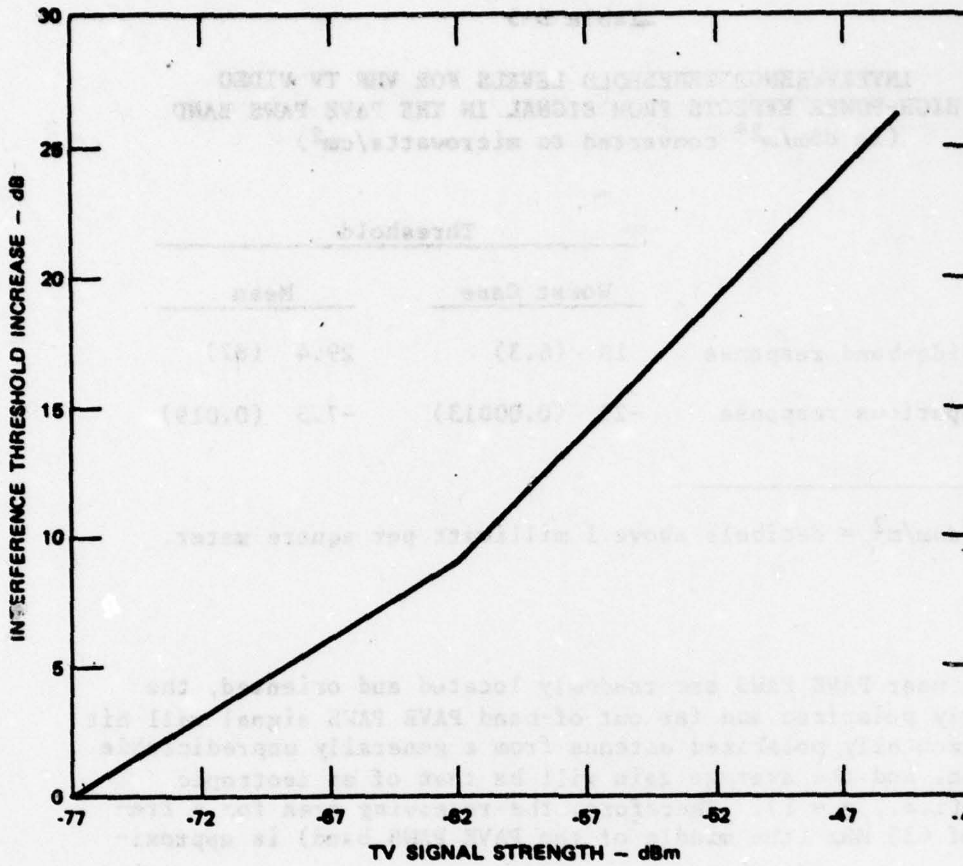



FIGURE D-7. INTERFERENCE THRESHOLD INCREASE FACTOR FOR TV SIGNAL STRENGTH HIGHER THAN -77 dBm

AD-A069 200 SRI INTERNATIONAL MENLO PARK CA F/G 6/6
ENVIRONMENTAL IMPACT STATEMENT - OPERATION OF THE PAVE PAWS RAD--ETC(U)
MAY 79 F08635-76-D-0132
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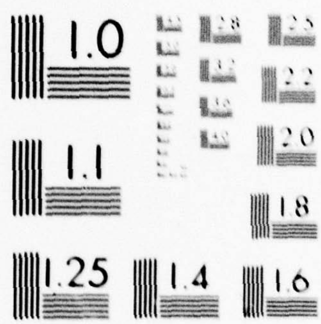


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table D-5

**INTERFERENCE THRESHOLD LEVELS FOR VHF TV VIDEO HIGH-POWER EFFECTS FROM SIGNAL IN THE PAVE PAWS BAND (in $dBm/m^2$[a] converted to microwatts/$cm^2$)**

| | Threshold | | | |
|---|---|---|---|---|
| | Worst Case | | Mean | |
| Wide-band response | 18 | (6.3) | 29.4 | (87) |
| Spurious response | -29 | (0.00013) | -7.3 | (0.019) |

[a] $dBm/m^2$ = decibels above 1 milliwatt per square meter.

antennas near PAVE PAWS are randomly located and oriented, the circularly polarized and far out-of-band PAVE PAWS signal will hit the horizontally polarized antenna from a generally unpredictable direction, and the average gain will be that of an isotropic antenna (i.e., $g = 1$). Therefore, the receiving area for a frequency of 435 MHz (the middle of the PAVE PAWS band) is approximately

$$a = 0.038 \ m^2,$$

and because the power density has already been converted to decibels, a similar conversion gives

$$A = 10 \log a = -14.2 \text{ dB relative to } 1 \ m^2.$$

Now the power (in dBm) at the TV set can be obtained by subtracting 14.2 dB, and about 2 dB for losses in the antenna lead (O'Connor, 1963), from the power flux density (in $dBm/m^2$). Applying this method to the mean wideband susceptibility threshold of Table D-5 yields a mean susceptibility threshold of 29.4 - 16.2 = 13.2 dBm, which is very close to the 11 dBm suggested by Conklin in Section D.3.1.2.1, p. D-21.

D.3.1.2.4 Summary of TV Receiver Susceptibility. Based on the foregoing analysis, our best estimate is that reception of VHF TV channels could be affected by PAVE PAWS signals greater than about 11 dBm at the antenna terminals regardless of the strength of the desired TV signal strength. Channel 10 will be particularly sensitive to PAVE PAWS signals in the frequency range 431 to 437

MHz. The effect is worse when the signal-to-interference level is lower.

The TV receiver susceptibilities can be expressed in terms of electromagnetic field quantities. The high-power effects presented in Table D-5 are already in power density terms. One can take the 11-dBm threshold suggested by Conklin (1974) and add 2 dB for TV receiver line loss plus 14.2 dB for the TV antenna aperture to obtain approximately 27 dBm/m$^2$ (50 microwatts/cm$^2$) as the field power density equivalent to an 11-dBm threshold.

The same method can be applied to the vertical scale of Figure D-6 (p. D-24) to determine that the 434-MHz power density that would affect the more-susceptible half of the TV receivers is about $-24 + 16 = -8$ dBm/m$^2$ (0.016 microwatts/cm$^2$) when the desired signal strength (at the receiver terminals) is -77 dBm. Now, because the concern is specifically with reception of TV Channel 10 in the area of PAVE PAWS, the Channel-10 signal strength is desired. According to the <u>Television Factbook</u> (1974), most of the Cape Cod peninsula is on or within the Grade A contour for WJAR Channel 10. This means that the median <u>predicted</u> TV field strength there is about E = 71 dB above 1 microvolt/m (0.0035 V/m). O'Connor (1965) relates the field strength to the voltage, $V_L$, across the receiver terminals, by

$$V_L = E + K_d + G - L$$

where $V_L$ and E are already defined, L is the loss in the antenna lead, G is the TV antenna gain in decibels relative to a dipole, and $K_d$ is called a dipole factor. For the Channel-10 frequency band (192 to 198 MHz), $K_d$ = -6 dB. The line loss will be about L = 2 dB and the gain of a typical good Yagi antenna will be about 9 dB relative to a dipole. Therefore, the median value of $V_L$ is about

$$V_L = 71 - 6 + 9 - 2 = 72 \text{ dB (1 microvolt)} = 3{,}981 \text{ microvolts,}$$

and the power level at the 300-ohm terminals is about

$$\frac{(3{,}981 \text{ microvolts})^2}{300} = 5.3 \times 10^{-5} \text{ mW} = -43 \text{ dBm.}$$

Figure D-7, which gives the TV signal strength correction factor for Figure D-6, indicates that for a TV signal strength of -43 dBm, we must increase the Channel-10 spurious-signal susceptibility by about 28 dB. Therefore, half of the TV sets would experience some perceptible effect when the PAVE PAWS power density is about $-8$ dBm/m$^2$ + 28 dB = +20 dBm/m$^2$ (10 microwatts/cm$^2$). Figure D-6 indicates that the more-susceptible TV sets may be affected by PAVE PAWS signals about 35 dB lower, or at about -15 dBm/m$^2$. Corroborating experimental work by MITRE (1978), using a Channel-10 signal of about the same strength as in

the Cape Cod area and a simulated PAVE PAWS signal, gives similar results. Three black-and-white TV sets had susceptibility thresholds of about -12 $dBm/m^2$ while a color set had a threshold of about -2 $dBm/m^2$.

The Channel-10 spurious-response frequencies lie in the band from 431 to 437 MHz. Six of the PAVE PAWS's 24 frequencies (see Table D-2, page D-12) are therefore capable of producing that spurious response. The Channel-10 response to the other 18 frequencies would be the same as that of the other TV channels. Therefore, only one third of the radar pulses are of a frequency that can cause the spurious response.

D.3.1.2.5 <u>The Television Environment on Cape Cod</u>. According to the <u>Television Factbook</u>, Cape Cod is part of the coverage areas of the television stations listed in Table D-6, p. D-30. The net weekly circulation figures, also taken from the <u>Television Factbook</u>, provide an estimate of the number of television households in the area that view the particular station at least once a week. A station's net weekly circulation in a county is quoted as more than 50%, 25-49%, or 5-24%. The figure can be misinterpreted. When the <u>Factbook</u> says that a station's net weekly circulation is greater than 50%, it does not mean that more than half of the viewers are watching that channel at a given instant; it simply means that more than half can be expected to watch it at some time in a week. The rest of those, it follows, do not watch it at all within the week.

The area of Cape Cod near Sandwich is on or near the Grade A service contour for all the listed stations except WSMW, Channel 27. At the Grade A contour, the median field strength, hitting a dipole at a height of 30 ft, must provide service, at the best 70% of the receiving locations, that the median observer would consider "acceptable" at least 90% of the time. The field strength given for the Grade A contour in handbooks (71 dB above 1 microvolt per meter for channels 7-13) is actually the median of a random variable. Because of location variations and time variations, the standard deviation for the predicted median field strength is almost 9 dB.

Estimating the extent of interference requires determining where the television receivers in the Cape Cod area are. A television household is a household having one or more television receivers. On the map of Figure D-8, the dots representing the locations of residents can also represent the locations of television households. Estimating 0.68 households per person, 97% of which are TV households, the smaller and larger dots can be used to represent about 66 TV sets and 330 TV sets, respectively.

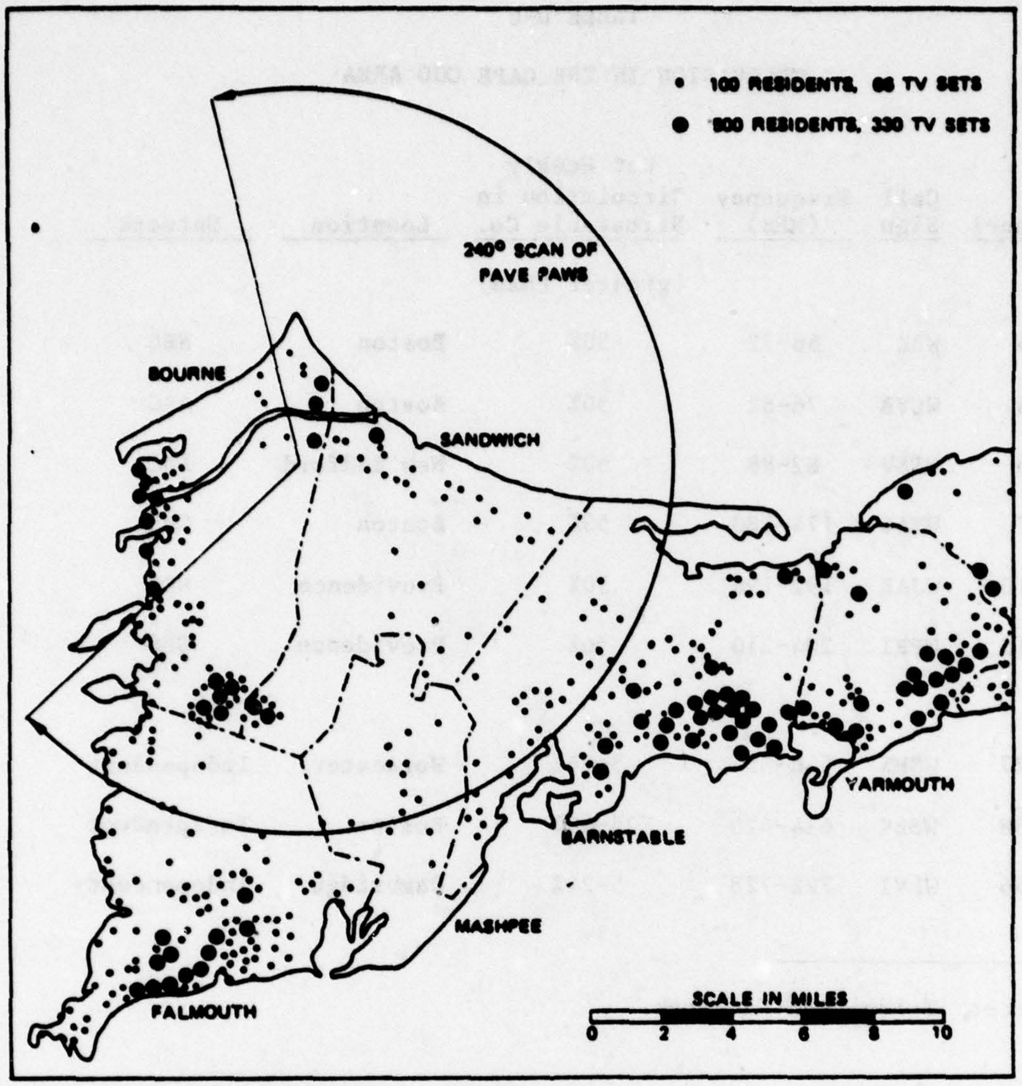


FIGURE D-8. AN ESTIMATE OF THE LOCATIONS OF TV RECEIVERS

TABLE D-6

TELEVISION IN THE CAPE COD AREA

| Channel | Call Sign | Frequency (MHz) | Net Weekly Circulation in Barnstable Co. (greater than) | Location | Network |
|---|---|---|---|---|---|
| 4 | WBZ | 66-72 | 50% | Boston | NBC |
| 5 | WCVB | 76-82 | 50% | Boston | ABC |
| 6 | WTEV | 82-88 | 50% | New Bedford | ABC |
| 7 | WNAC | 174-180 | 50% | Boston | CBS |
| 10 | WJAR | 192-198 | 50% | Providence | NBC |
| 12 | WPRI | 204-210 | 50% | Providence | CBS |
| 27 | WSMW | 548-554 | 5-24% | Worcester | Independent |
| 38 | WSBK | 614-620 | 25-49% | Boston | Independent |
| 56 | WLVI | 722-728 | 5-24% | Cambridge | Independent |

Source: Television Factbook.

D.3.1.2.6 Effects of PAVE PAWS on Cape Cod TV Reception. The two preceding subsections discussed TV receiver susceptibility in terms of PAVE PAWS power density and the TV environment in the Otis AFB area. Information of both kinds must be combined to determine the probable effects of PAVE PAWS on TV reception in the area.

TV receivers, being essentially ground-based objects, may be illuminated by PAVE PAWS' higher-order sidelobes. Figure D-9 shows the pulse power density for the rms value of these sidelobes for the basic PAVE PAWS system. The top curve shows the maximum possible pulse power density, taking into account only the power loss that results from spreading the available energy over a greater area at a greater distance. This curve applies to TV receivers in a clear line-of-sight path to a face of PAVE PAWS.

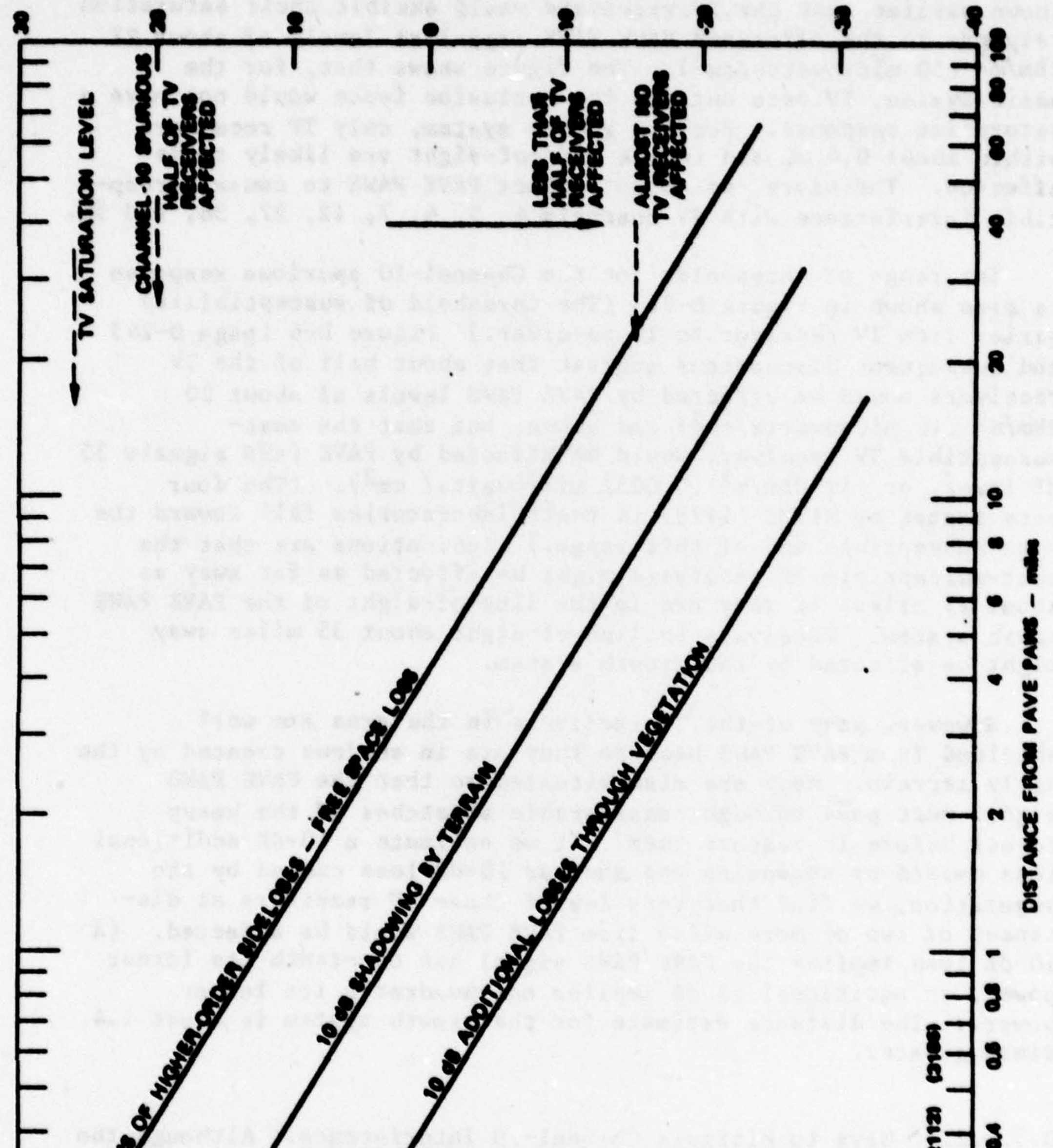


FIGURE D-9. PAVE PAWS INTERFERENCE TO TV, BASIC SYSTEM ++

Under the growth option, the curve would be 3 dB higher. It was shown earlier that the TV receivers would exhibit their saturation response to the off-tuned PAVE PAWS signal at levels of about 27 dBm/m$^2$ (50 microwatts/cm$^2$). The figure shows that, for the basic system, TV sets outside the exclusion fence would not have a saturation response. For the growth system, only TV receivers within about 0.4 mi and in the line-of-sight are likely to be affected. Therefore, we do not expect PAVE PAWS to cause perceptible interference with TV channels 4, 5, 6, 7, 12, 27, 38, and 56.

The range of thresholds for the Channel-10 spurious response is also shown in Figure D-9. (The threshold of susceptibility varies from TV receiver to TV receiver.) Figure D-6 (page D-24) and subsequent discussions suggest that about half of the TV receivers would be affected by PAVE PAWS levels of about 20 dBm/m$^2$ (10 microwatts/cm$^2$) and above, but that the most-susceptible TV receivers would be affected by PAVE PAWS signals 35 dB lower, or -15 dBm/m$^2$ (0.0032 microwatts/ cm$^2$). (The four sets tested by MITRE (1978) in their laboratories fall toward the more-susceptible end of this range.) Indications are that the most-susceptible TV receivers might be affected as far away as about 25 miles, if they are in the line-of-sight of the PAVE PAWS basic system. Receivers in line-of-sight about 35 miles away might be affected by the growth system.

However, many of the TV receivers in the area are well shielded from PAVE PAWS because they are in shadows created by the hilly terrain. Many are also situated so that the PAVE PAWS signal must pass through considerable stretches of the heavy forest before it reaches them. If we estimate a 10-dB additional loss caused by shadowing and another 10-dB loss caused by the vegetation, we find that very few of these TV receivers at distances of two or more miles from PAVE PAWS would be affected. (A 10-dB loss implies the PAVE PAWS signal has one-tenth its former power, an additional 10 dB implies one-hundredth its former power.) The distance estimate for the growth system is about 1.4 times greater.

D.3.1.2.7 Ways to Mitigate Channel-10 Interference. Although the potential exists for interference with Channel 10 in the vicinity of Otis AFB, a number of steps might be taken to alleviate the situation.

First, because this analysis is based on a very limited amount of real data, the interference may be more or less severe than the analysis suggests. Only 12 TV receivers were measured in the late 1960's; PRFs and pulsewidths other than those of PAVE PAWS were used, although the radar frequency band was the same. Susceptibility is also dependent on the TV signal strength. Although the best available estimate was used for the median signal strength, in particular situations it could be much higher or lower.

Furthermore, the propagation of the PAVE PAWS signal will be highly variable except when line-of-sight. Thus, the extent of the problem with Channel 10 could be somewhat different than the analysis shows. In the first approximately 225 hours of actual operation of the radar, using both faces and in the frequency switching mode, no cases of interference to TV had been brought to the attention of the PAVE PAWS program office.

The Electromagnetic Compatibility Analysis Center (ECAC) has experimented with simple filters to attach to the back of a TV receiver. Figure D-10 shows a sketch of the most simple type; it is just a 5 3/8-inch piece of flat TV lead-in cable connected as shown. This filter, which the Air Force would provide on request, can reduce susceptibility by a factor of more than 100 (20 dB). Experiments indicate that a slightly more sophisticated filter can attenuate the PAVE PAWS signal by a factor of more than 10,000 (40 dB). The effect of this filter would be to increase the susceptibility thresholds of Figure D-9 by 40 dB. Then, reception might not be affected for TV receivers as close as the exclusion fence for the basic system and about a half-mile for the growth system. (This compares with distances of about 25 and 35 miles without any filter.)

The Channel-10 problem results from PAVE PAWS operation only in the band from 431 to 437 MHz, which includes only 6 of the 24 PAVE PAWS channels. If operational requirements permit discontinuing use of those six channels, there would be no spurious-signal problem on Channel 10. A less radical alternative may be possible, following experiments to determine which of the 6 channels are most disruptive to TV reception. The PAVE PAWS signal frequencies causing spurious responses near the TV picture carrier are probably much more of a concern than are the others. Perhaps deleting only one or two PAVE PAWS channels in the 431 to 437 MHz band (when it would not jeopardize PAVE PAWS operations) would accomplish the objective of alleviating the spurious-signal problem for Channel 10.

### D.3.1.3 High-Power Effects to Systems other than TV

High-power interference with a system results from the direct coupling of the interfering signal to internal circuits and components via the equipment case, antenna leads, power line, or signal leads. We do not expect that high-power effects will be a problem. Donaldson (1978) describes high power effects as being "significantly different from the classical, frequency dependent EMI problems (co-channel interference, spurious responses, intermodulation, etc.)." As Moss (1978) did, we will divide the systems potentially subject to interference into civilian and military.

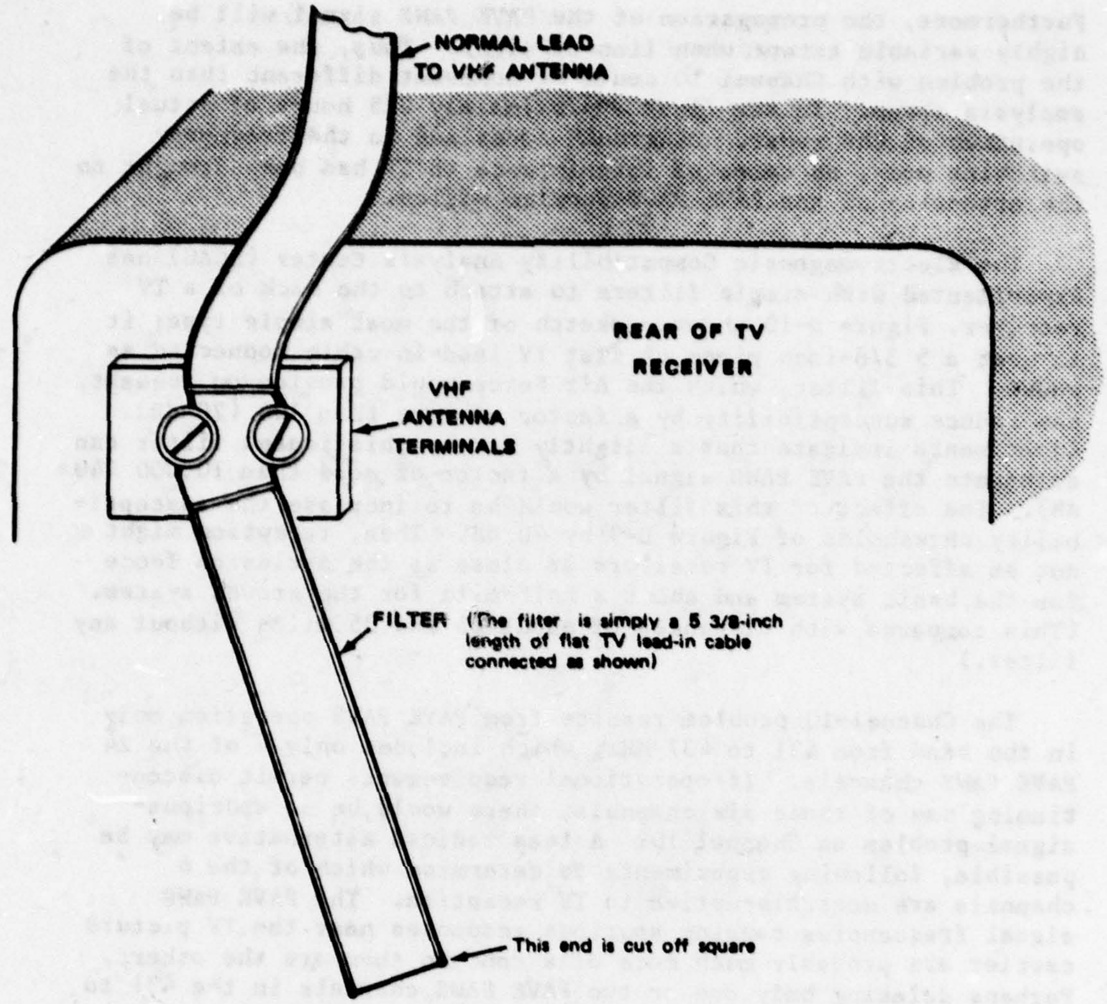


FIGURE D-10. FILTER TO REMOVE PAVE PAWS SIGNALS FROM TV RECEIVER

D.3.1.3.1 <u>Civilian Systems</u>. Moss has stated that high power interference "can occur in civilian electronics equipment when the peak power density is in excess of 30 $dBm/m^2$" (100 microwatts/$cm^2$).

Donaldson (1978) sampled 20 home stereo systems, each consisting of an AM/FM-stereo receiver, a tuner, an amplifier, a record changer, and speakers. All were solid state. Four major manufacturers were represented. The units covered a wide cost range and differed widely in chassis configuration. Donaldson's tests were in the frequency range from 400 to 450 MHz, but he did not present any further details of the interference source for reasons of national security. He found wide variations from unit to unit in thresholds for minimum perceptible interference. For all operating modes (FM/FM-stereo, AM, phonograph, or tape), the average threshold was about 7 $dBm/m^2$ (0.5 microwatts/$cm^2$). Susceptibility varies widely (by a factor of 100 (20 dB)) with orientation and is also affected by the level of the desired signal.

Measurements have been made on a transistor AM receiver. At approximately 450 MHz, thresholds were about 22 to 32 $dBm/m^2$ (16 to 160 microwatts/$cm^2$). Varying the pulse width and PRF had little effect on the thresholds.

Tests were also made on a single solid-state AM/FM broadcast receiver. A threshold of about 20 $dBm/m^2$ (10 microwatts/$cm^2$) was noted at about 450 MHz for the pulse width and PRF used. We estimate that the threshold might be closer to 14 $dBm/m^2$ (2.5 microwatts/$cm^2$) at a pulse width of about 10 ms and a PRF of about 20 pps.

Tests were made on three "inexpensive phonographs and a tape recorder" using a PRF of 40 pps with pulse widths of 0.2 ms, 1.0 ms, and 6.0 ms. At the 6-ms pulse-width the susceptibility thresholds ranged from 0 to 11 $dBm/m^2$ (0.1 to 1.3 microwatts/$cm^2$).

Susceptibility of 16 hearing aids ranged from about -17 to +38 $dBm/m^2$, with a median of about +16 $dBm/m^2$ (0.002 to 630 microwatts/$cm^2$ with median 4 microwatts/$cm^2$).

Tests were also made on a single UHF land mobile transceiver operating in the 450 to 470 MHz band (adjacent to the PAVE PAWS band). The threshold of susceptibility for the radar characteristics used was about 42 $dBm/m^2$ (1,600 microwatts/$cm^2$). The threshold for susceptibility to PAVE PAWS would probably be about 34 $dBm/m^2$ (250 microwatts/$cm^2$).

Two VHF FM land mobile transceivers were tested. They were different solid-state models, by the same manufacturer, that operate in the 136 to 174 MHz range. Tests were made not only to determine the threshold of interference with the desired signal,

but also to determine whether the interfering signal could be made to break squelch. The thresholds when they were receiving were about 16 and 25 $dBm/m^2$ (4 and 32 $microwatts/cm^2$) for the two units. When they were not receiving, the interference could not break squelch at levels up to the maximum available power density of 37 $dBm/m^2$ (500 $microwatts/cm^2$). Curves were not provided, in this instance, that would permit us to extrapolate these data to the pulse width and PRF of PAVE PAWS.

A single high fidelity tape recorder was tested. After adjusting for pulse width and PRF, we judge that its susceptibility threshold for the PAVE PAWS signal would be about 6 $dBm/m^2$ (0.4 $microwatts/cm^2$).

High-power effects on TV were discussed in Section D.3.1.2.3 (page D-23).

D.3.1.3.2 Military Communications Systems. Ross (1978) states that the threshold criterion for military electronics is 40 $dBm/m^2$ (1,000 $microwatts/cm^2$).

Tests were made on two military ground receivers, an AN/GRR-23 and an AN/GRR-24, both of which are solid state, single-channel HF/VHF AM receivers. The interfering signal pulse-width was 80 microseconds and the PRF was 1,250 pps. Susceptibility thresholds for high-power effects were greater than 42 $dBm/m^2$ (1,600 $microwatts/cm^2$), and a spurious response was found in the AN/GRR-23 for an interfering frequency of 439.3 MHz at 41 $dBm/m^2$ (1,300 $microwatts/cm^2$).

Measurements were made on a single FM mobile unit. This was the receiver portion RT-246/VRC of an AN/VRC-12. No high-power effects were noted at around 430 MHz at field levels as high as almost 40 $dBm/m^2$ (1,000 $microwatts/cm^2$).

D.3.1.3.3 Susceptibility to PAVE PAWS. All the systems described in this analysis are ground-based systems, which would likely be exposed to the high-order sidelobe structure of the PAVE PAWS beam. The sparse susceptibility information just described is summarized in Table D-7. If we compare these levels with the top curve in Figure D-9 (page D-31), indicating a direct line-of-sight path to PAVE PAWS, we see that high-power effects on civilian systems seem unlikely. If shielding by terrain features and losses through vegetation are considered, such effects seem even more unlikely at the distances from PAVE PAWS at which such systems would operate. Stronger statements than this cannot be made for two reasons. First, the susceptibility testing that has been done did not use the particular pulse-width and PRF parameters applicable to PAVE PAWS; thresholds are dependent not only on frequency, but also on pulse width and PRF. Second, only a very small sample of

Table D-7

**SUMMARY OF SUSCEPTIBILITY THRESHOLDS FOR HIGH-POWER EFFECTS**

| System Type | Units Tested | Threshold $(dBm/m^2)$ | Threshold Micro-watts/$cm^2$ |
|---|---|---|---|
| Civilian | | | |
| AM/FM, record changer, etc. | 20 | 7 (average) | 0.5 |
| AM receiver | 1 | 22-32 | 16-160 |
| AM/FM receiver | 1 | 20 (approx.) | 10 |
| "Inexpensive" phonograph | 3 | 0-11 (range) | 0.1-1.3 |
| Hearing aids | 16 | 16 (median) | 4 |
| UHF FM land mobile receiver | 1 | 34 (approx.) | 250 |
| VHF FM land mobile receiver | 2 | 16, 25 | 4, 32 |
| Hi-Fi tape system | 1 | 6 | 0.4 |
| Military | | | |
| HF/VHF AM receiver | 2 | greater than 42 | greater than 1,600 |
| Mobile FM receiver | 1 | greater than 40 | greater than 1,000 |

electronic units has been tested, and their responses are not necessarily representative of those of all the systems that would be exposed.

## D.3.1.4 Interference to Ground-Based Systems from PAVE PAWS

D.3.1.4.1 Factors Governing Interference. The following major factors govern interference from PAVE PAWS to a distant receiver:

- o Effective radiated power (ERP) of PAVE PAWS, including harmonic and spurious suppression of the radar.

- o Separation distance, d, between PAVE PAWS and the receiver.
- o Frequency separation between the PAVE PAWS operating frequencies and the frequency of the receiver.
- o Noise threshold of the receiver.
- o Harmonic and spurious rejection of out-of-band signals in the receiver, antenna height, siting, gain (directivity), and polarization.
- o Irregularities in terrain and signal-power loss in foliage.

D.3.1.4.1.1 <u>Basic Transmission Equation</u>

The undesired (interfering) power $I_R(d)$ at the terminals of a receiver at distance d from PAVE PAWS is given (in dBm) by

$$I_R(d) = P_T - L_T + G_T - L_b(d) - L_{bf} + G_R - L_R, \text{ where}$$

$I_R(d)$ = undesired received power (dBm)

$P_T$ = PAVE PAWS transmitter power (dBm)

$L_T$, $L_R$ = insertion loss of transmission line for transmitter and receiver

$G_T$, $G_R$ = antenna gains for transmitting and receiving antennas, relative to isotropic (dBi)

$L_b(d)$ = median basic transmission loss at distance d (dB)

$L_{bf}$ = median foliage loss (dB)

d = separation distance between transmitter and receiver (km).

D.3.1.4.1.2 <u>Effective Radiated Power (ERP)</u>. For the PAVE PAWS radar, the effective radiated power, ERP, is given (in dBm) by

$$ERP = P_T + G_T.$$

Feed line insertion loss, $L_T$, is not applicable to PAVE PAWS, and therefore was not included.

The pulse ERP for PAVE PAWS is contained in the radar specifications (Specification, PAVE PAWS Program Office) and is

summarized in Table D-8. ERP, the rms value for individual pulses, is not time averaged. For electromagnetic interference (EMI) analysis of ground-based receivers, the rms gain of the higher-order antenna sidelobes (+0 dBi) was used. These sidelobes are present during each radiated pulse, and using the rms value is equivalent to averaging over their various amplitudes.

D.3.1.4.1.3 <u>Median Basic Transmission Loss ($L_b$)</u>. The basic transmission loss ($L_b$) is defined as the loss, in dB, between isotropic antennas physically located at the same places as the actual antennas. This loss is a function of several variables, including the distance between the antennas, the frequency, the antenna heights, the electrical properties of the ground, the roughness of the terrain, the foliage (discussed separately), and the refractive index of the air. Predicted basic transmission loss for a given distance is not a strictly deterministic number, but is actually a distribution that has a central value (median) and considerable variability about that value. The median value is commonly used to analyze the performance of radio systems, and

Table D-8

EFFECTIVE RADIATED POWER FOR PAVE PAWS BASIC SYSTEM[a] FOR HIGHER-ORDER SIDELOBES

| | In-band | Out-of-band |
|---|---|---|
| Pulse power ($P_T$)[b] | 88 dBm | Not Applicable |
| Harmonic/spurious suppression | Not Applicable | 90 dB[d] |
| Antenna Gain ($G_T$) | | |
| Main beam (38 dBi) | | |
| First sidelobe (18 dBi) | | |
| Higher-order sidelobes (0 dBi)[c] | 0 dBi | 0 dBi |
| ERP for higher-order sidelobes | 88 dBm | -2 dBm |

[a] The ERP for the growth-system higher-order sidelobes is 3 dB greater than for the basic system. For main beam and first sidelobe, the difference is 6 dB.

[b] $P_T$ is rms power during individual pulses.

[c] Rms gain of higher-order sidelobes.

[d] See Table D-9, p. D-46 for additional information.

is used here. Anomalous propagation conditions, such as ducting caused by temperature inversions, occur so infrequently as to be of little concern. Ducting of main-beam or first-sidelobe energy will never occur. Only energy at elevation angles near zero degrees can be ducted to increase PAVE PAWS signal levels at locations beyond the horizon. (Luczak et al., 1976; NAS, 1979). +

Median basic transmission loss can be calculated from radio propagation models. The Longly-Rice propagation loss model (Rice and Longley, 1968) was obtained from the Institute of Telecommunication Sciences (ITS), Boulder, Colorado, and was used for predictions of median basic transmission loss. The model is the best general-purpose model available for predicting long-term median radio transmission loss at VHF and higher frequencies over irregular terrain (Jennings and Paulson, 1977). The model predictions agree well with experimental data (Jakes, 1974).

The model predicts median basic transmission loss for three regions as distance from the source increases: line-of-sight region, diffraction region, and troposcatter region. The diffraction and troposcatter regions occur at distances beyond the radio horizon; the predictions account for the infrequency of ducting of higher-order sidelobe energy there mostly by increasing the standard deviation of the predicted median loss.

Figure D-11 gives basic transmission loss over seawater as a function of distance for elevated antennas. The overwater condition corresponds to north-south paths from PAVE PAWS. Antenna heights are relative to mean sea level.

Figure D-12, p. D-42, gives basic transmission loss over irregular terrain (E-W paths) having a terrain roughness factor, or interdecile range, of 50 m. The interdecile range is defined as the difference in elevation (in meters) between the 90th and 10th percentile points on a cumulative distribution of elevations in the area. A terrain roughness of 50 m corresponds to rolling plains (Jakes, 1974). Ground constants applicable to the Cape Cod area were used. For this figure, antenna heights are given relative to ground level. Distance to the radio horizon is indicated on each of these figures.

D.3.1.4.1.4 <u>Foliage Loss ($L_{bf}$)</u>. Foliage and vegetation, such as trees, provide additional attenuation to radio signals. The loss depends on the density of the trees and extent of foliation along the path. For very short paths, with <u>both</u> transmitting and receiving antennas in foliage (full leaf), the loss factor is approximately 0.1 dB/m at 435 MHz (La Grone, 1960).

Total attenuation over radio paths of various length has been measured. At 400 MHz, with each antenna in foliage, total loss has been measured at 20-25 dB (Doeppner, 1972). Foliage loss at

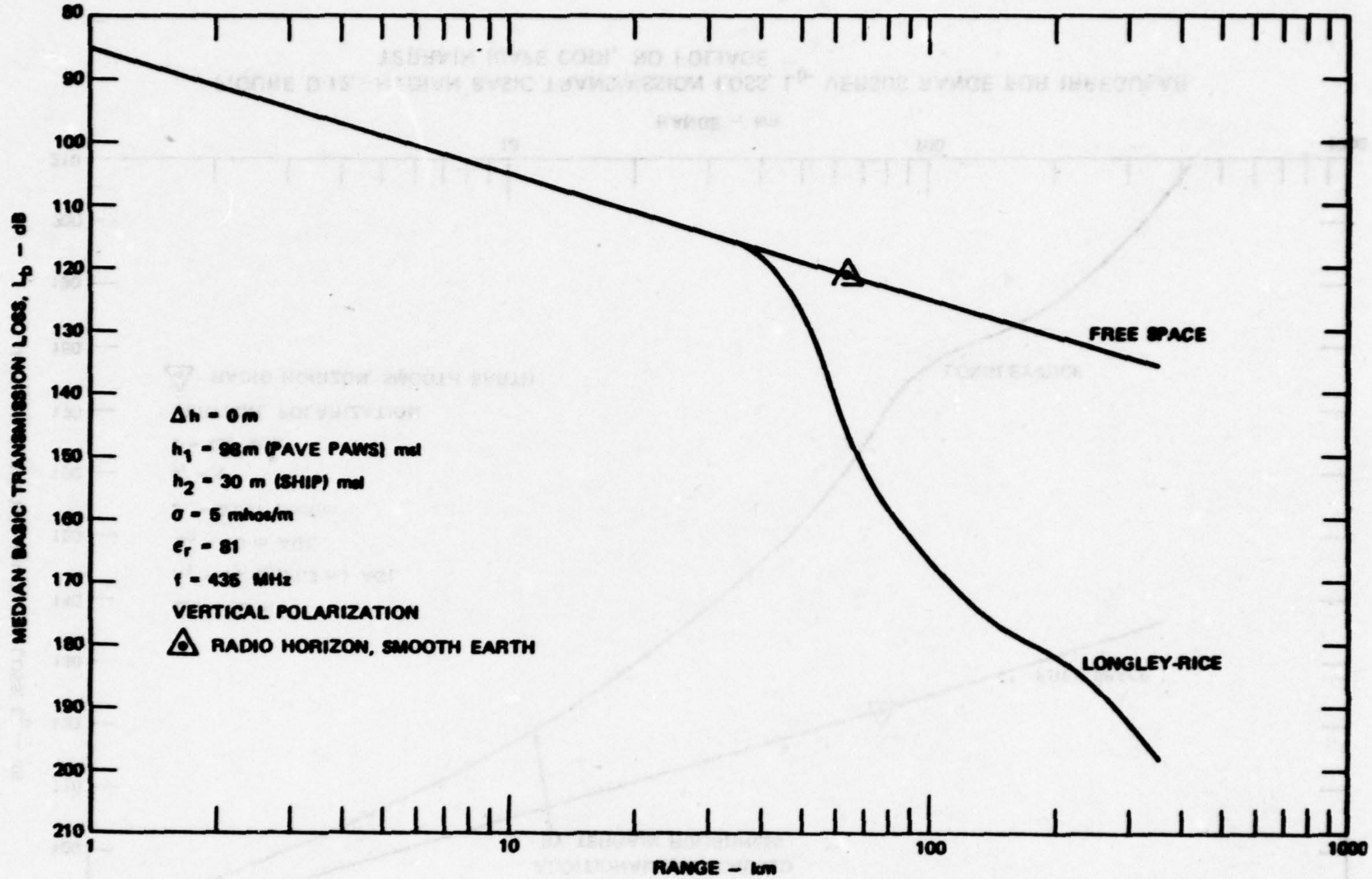


FIGURE D-11. MEDIAN BASIC TRANSMISSION LOSS, $L_b$, VERSUS RANGE FOR ELEVATED ANTENNAS, SEA PATH

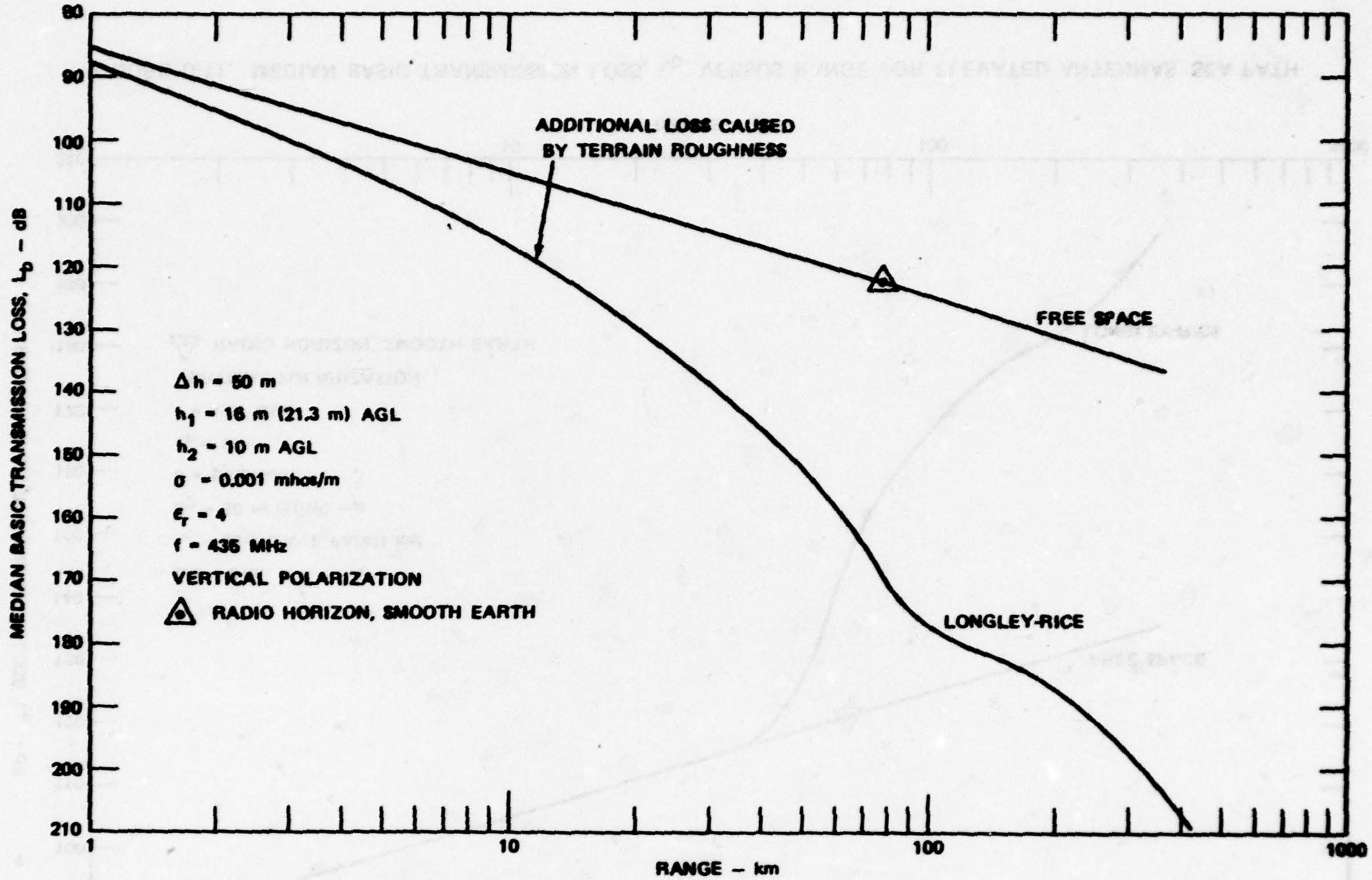


FIGURE D-12. MEDIAN BASIC TRANSMISSION LOSS, $L_b$, VERSUS RANGE FOR IRREGULAR TERRAIN (CAPE COD), NO FOLIAGE

500 MHz through a patch of woods 500 ft thick was measured in summer (19 dB) and winter (15 dB) with vertical polarization (Trevor, 1940). Head (1960) considered the effect of thickness of trees between the path terminals, but with the receiver in the clear. Measurements at 405 MHz show the signal to be much attenuated near the woods, and that considerable clearing distance between wood and receiver is required for recovery. The signal increases in proportion to the logarithm of the clearing depth, expressed in miles. At clearing depths of 0.01 and 1 mi, attenuations are 35 and 12 dB, respectively (Head, 1960). That is, at those clearing depths, the signal is reduced to 1/3,200th and 1/16th of its former strength.

Because of the presence of both deciduous and evergreen trees in the PAVE PAWS area, it is desirable to estimate attenuation caused by foliage. PAVE PAWS is located in a clearing on a hill surrounded by low, dense, scrub oak and pine trees. Radio paths beyond the clearing often must pass through heavily foliated areas. We estimate the additional path attenuation through the foliage at about

$$L_{bf} = 10 \text{ dB}.$$

This loss factor was used in subsequent calculations.

D.3.1.4.1.5 Receiver Considerations. Various characteristics of the receiver affect its susceptibility to interference. These include the gain of the receiver antenna, $G_R$, toward the interfering source, the minimum power level required at the terminals of the receiver for the receiver to operate (usually just above the receiver noise level), the rejection characteristics of the front end of the receiver to out-of-band signals, the RF (or IF) bandwidth of the receiver, and the required interference-to-noise ratio for a given level of receiver degradation.

In some of the following analysis, the signal detection threshold (required power level) is taken to be the antenna thermal noise level. For ground communication receivers with an assumed effective noise temperature of 290 K, the antenna noise transferred to the receiver is -174 dBm per Hertz of bandwidth.

For voice FM receivers, the receiver noise level does not represent a realistic detection level. The true working threshold, often called the FM improvement threshold (or FM breaking point), occurs when the power of the signal exceeds the power of the noise by 10 dB or more (GTE Lenkurt, 1972). These receivers have a squelch circuit with a threshold that can be set above the noise level to turn off the speaker when no signal is being received. For analysis of FM voice receivers, a required interference-to-noise power threshold of 12 dB was assumed.

For the radars analysed (at Millstone, MA and Montauk Point, NY) the equivalent system noise figure (expressed in Kelvins) was used, and converted to a minimum required power level, in dBm. For radar receivers, it was assumed that if the PAVE PAWS signal exceeded this power, interference would be detected by the radar receiver.

It should be noted that setting a receiver system's threshold of susceptibility to the PAVE PAWS signal at the receiver system noise level is a very conservative criterion, in that it assumes that the desired signal is also at or below the noise level.

The level of the desired signal at the receiver is highly variable, and difficult to estimate. In some cases, however (airborne UHF/AM, and mobile UHF/FM), the desired signal power was estimated and the ratio of the desired signal to the PAVE PAWS signal was computed. If that ratio is large, communications can take place in the presence of PAVE PAWS interference.

D.3.1.4.2 Interference Analyses. The difference between the minimum power required for receiver operation, and the interfering PAVE PAWS power, $I_R(d)$, can be computed. The following terms are defined at the input terminals to the receiver:

$P_{Rmin} = R_N + INR$, where

$P_{Rmin}$ = The minimum power (desired or undesired) that can be detected by the receiver (dBm).

INR = The ratio of the interfering signal to the receiver noise (dB). There will be no interference to the receiver unless the undesired signal exceeds $R_N$ + INR).

$R_N$ = Receiver noise level (dBm)

The receiver noise level can be expressed as

$R_N = 10 \log KT_oB + F + 30$, where

$K = 1.38 \times 10^{-23}$ Joules/degree K.

$T_o$ = 290 deg K.

B = receiver noise power bandwidth (Hz).

F = receiver noise figure (dB).

These data were not available for all cases, so $R_N$ (in dBm) was often estimated.

A receiver may reduce the interfering signal power to a lower effective level. The effective level of the interfering signal, $I_R(d)_{EFF}$, is expressed as follows:

$$I_R(d)_{EFF} = I_R(d) - FDR, \text{ in dBm, where}$$

$I_R(d)_{EFF}$ = effective power of the interfering PAVE PAWS signal at the receiver terminals (dBm).

$I_R(d)$ = actual power from PAVE PAWS at the receiver terminals (dBm).

FDR = frequency-dependent rejection provided by the receiver with respect to the interfering emission spectrum (dB).

Receiver FDR was considered for UHF/FM and AM receivers operating adjacent to the PAVE PAWS band. It was assumed that the bandwidth of those receivers was small compared with the emission spectrum of PAVE PAWS. The FDR was computed by the Electromagnetic Compatibility Analysis Center (ECAC) (Moss, 1978). The most commonly occurring PAVE PAWS pulse is the short-range surveillance pulse, which is 300 microseconds long. Nine such pulses occur in a 54-ms resource, at an average repetition rate of 28.3 pulses per second. The FDR from this pulse spectrum was determined by ECAC and is summarized in Table D-9.

The power levels of the desired and the undesired signals are compared by computing the margin, M(d), which is defined as

$$M(d) = P_{Rmin} - I_R(d)_{EFF}, \text{ in dB, where}$$

M(d) = the amount, in dB, by which the minimum required receiver power exceeds the effective power of the interfering signal.

Combining terms, margin becomes

$$M(d) = R_N + INR - I_R(d) + FDR \quad dB.$$

The sign of the margin indicates the presence or absence of interference to the system. If the receiver noise level plus the INR and FDR terms exceed the interfering signal, $I_R(d)$, from PAVE PAWS, the margin is positive and no interference is detected by the receiver. Conversely, if $I_R(d)$ exceeds the other terms, the receiver will detect interference (negative margin). The effect of interference on a receiver system depends on that system, and requires a subjective evaluation.

Table D-9

ATTENUATION OF EMISSION SPECTRUM FROM PAVE PAWS
CAUSED BY FREQUENCY SEPARATION (FDR)
FOR SHORT-RANGE SURVEILLANCE PULSE

| Frequency Separation[a] (MHz) | Attenuation from Frequency Separation -- FDR (dB) |
|---|---|
| 0 | 0 (no attenuation) |
| less than 0.04 (40 KHz) | 0 |
| 0.06 (60 KHz) | 10 |
| 0.1 (100 KHz) | 28 |
| 0.5 | 40 |
| 1.0 | 48 |
| 2.0 | 52 |
| 4.0 | 58 |
| 10 | 75 |
| 25 | 90 |
| greater than 25 | 90 |

[a] Between PAVE PAWS frequency and out-of-band frequency.

Source: Moss, 1978. Emission spectrum of short-range surveillance pulse.

D.3.1.4.3 Frequency Bands. The following section approaches the analysis of systems on a frequency-band by frequency-band basis. Frequency assignments are made, by the FCC and by military frequency management activities, within allocated bands listed in the National Table of Frequency Allocations (OTP, 1976). The bands are summarized in Table D-10.

A number of receivers within 100 miles of Otis AFB have been identified and analyzed on a case-by-case basis. A list of the receivers, their operating frequencies, and distances from PAVE PAWS is given in Table D-11, p. D-48. A complete table containing the values used for the analysis is contained in Table D-12 (p. D-49).

Table D-10

**FREQUENCY BANDS BELOW AND ABOVE PAVE PAWS OPERATIONAL BAND (in MHz)**

| | | |
|---|---|---|
| 88-108 | Commercial FM band | |
| 138-174 | Otis AFB non-tactical band | |
| 225-399.9 | Military Air-ground UHF band | |
| 400-406.1 | Lower adjacent bands | |
| 406.1-420 | | |
| 420-450 | PAVE PAWS frequency band | |
| 450-470 | Upper adjacent bands; land-mobile service | |
| 470-806 | | |
| 840-900 | Second | PAVE PAWS harmonic bands |
| 1,260-1,350 | Third | |
| 1,680-1,800 | Fourth | |
| 2,100-2,250 | Fifth | |

Source: Moss, 1978.

Table D-11

RECEIVERS ANALYZED

| Case | Location | Frequency (MHz) | Distance from PAVE PAWS (mi) | Interference Predicted from PAVE PAWS[a] Basic | Growth |
|---|---|---|---|---|---|
| 1 | Otis flight facilities | 372.2 | 6 | No | No |
| 2 | Fire tower, Otis AFB | 381.4 | 3 | No | No |
| 3 | Aircraft above Otis AFB | 399.9 | 6 | I | I |
| 4 | Base station, Boston | 419.325 | 36 | No | No |
| 5/5a | Ionospheric Radar, Westford Mass. (main beam or sidelobe) | 440.0 | 77 | S[b] | S |
| 6 | Air Search Radar, Montauk, N.Y. (main beam and sidelobes) | 425-450 | 84 | S[b] | S |
| 7 | Base station, Barnstable | 453.7 | 15.6 | No | No |
| 8 | Microwave Receiver | 1,739 | 3.2 | No | No |

[a] Symbols used:
- No = no interference predicted
- I = the interference is not predicted to cause significant operational impact
- S = significant impact is predicted

[b] Although interference was predicted, none is being experienced.

Table D-12

TERMS USED TO DETERMINE MARGIN (PAVE PAWS)

| Case | Source | Receiver | ERP (dBm) | Frequency (MHz) | Distance (km) | $L_b$ (dB) | $L_{bf}$ (dB) | $G_r$ (dBi) | $I_r(d)$ (dBm) | $PR_{min}$ (dBm) | INR (dB) | FDR (dB) | Margin[a] (dB) Basic | Margin[a] (dB) Growth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | PAVE PAWS | Otis AFB | 88 | 399.9 | 9.6 | 116 | 10 | + 3 | - 35 | -107. | 0 | 90 | +18 | +15 |
| 2 | PAVE PAWS | Fire Tower | 88 | 381.4 | 4.8 | 106 | 10 | + 3 | - 25 | -107. | 0 | 90 | + 8 | + 5 |
| 3 | PAVE PAWS | Aircraft (4000 ft, Otis) | 88 | 399.9 | 9.6 | 104 | 0 | 0 | - 16 | -107. | 0 | 90 | - 1 | - 4 |
| 3a | Otis UHF/AM ground Tx | Aircraft, (4000 ft, Otis) | 43 | 399.9 | 1.2 | 88 | 0 | 0 | - 45 | -107. | 0 | 0 | NA | NA |
| 4 | PAVE PAWS | Base Station, Boston | 88 | 419.3 | 58. | 158 | 10 | | - 72 | -117. | 12 | 52 | +19 | +16 |
| 4a | Mobile Tx, Otis | Base Station, Boston | 50 | 419.3 | 58. | 158 | 10 | + 8 | -110 | -117. | 12 | 0 | NA | NA |
| 4b | PAVE PAWS | Mobile Rx | 88 | 419.3 | 15. | 134 | 10 | + 3 | - 53 | -117. | 12 | 52 | 0 | NA |
| 5 | PAVE PAWS | Millstone Radar, on-axis (150' dish) | 88 | 440. | 123. | 180 | 10 | +44 | - 58 | -132.5 | 0 | 0 | -74 | -77 |
| 5a | PAVE PAWS | Millstone Radar Sidelobe (150' dish) | 88 | 440. | 123. | 180 | 10 | 0 | -102 | -132.5 | 0 | | -30 | -33 |
| 6 | PAVE PAWS | AN/FPS-35 Montauk Pt. On-axis | 88 | co-channel | 134. | 175+ 10 | 10 | +32 | - 75 | -129. | 0 | 0 | -54 | -57 |
| 6a | PAVE PAWS | AN/FPS-35 Sidelobe | 88 | co-channel | 134. | 175+ 10 | 10 | + 6 | -101 | -129. | 0 | 0 | -29 | -32 |
| 7 | PAVE PAWS | Barnstable Co. UHF/FM Base Station | 88 | 453.7 | 25. | 135 | 10 | + 8 | - 49 | -117. | 12 | 63 | + 7 | + 4 |
| 7a | PAVE PAWS | Barnstable Co. Mobile | 88 | 453.7 | 8. | 123 | 10 | + 3 | - 42 | -117. | 12 | 63 | 0 | NA |
| 8 | PAVE PAWS Fourth Harmonic | Coast Guard Microwave | -2 | 1.7GHz | 5.1 | 111.5 | 0 | + 5 | -108.5 | - 99.4 | 0 | 0 | + 9 | + 6 |

[a]Positive margin implies no interference expected. NA = not applicable.

### D.3.1.4.3.1 225-399.9 MHz Band

Case 1: UHF/AM Receiver. A UHF/AM receiver operating on 372.2 MHz is located at Otis AFB 6 miles from PAVE PAWS. The following terms were used to calculate interference, and are summarized in a worksheet contained in Table D-13. The values and their sources are

ERP = 88 dBm (Radar specification)

$L_b$ = 116 dB (Longley-Rice model. See Figure D-12, p. D-42)

$L_{bf}$ = 10 dB (assumed)

$G_R$ = 3 dBi (assumed)

$R_N$ = -107 dBm (1 microvolt sensitivity)

FDR = 90 dB (48 MHz offset from nearest PAVE PAWS frequency)

INR = 0 dB (assumed).

No interference is expected from either the basic or the growth system. The effective PAVE PAWS power does not exceed the minimum required receiver power for detection. The calculated margin is +18 dB for the basic system, and +15 dB for the growth system, implying that interference is highly unlikely.

Case 2: Fire Tower. A UHF/AM transceiver operating on 381.4 MHz is located 3 miles from PAVE PAWS at the fire tower on the base. The same terms were used in the analysis as for the preceding case, except that now $L_b$ = 106 dB.

Margin was calculated at +8 dB for the basic system and +5 dB for the growth system, implying that interference would be very unlikely for either system. The effect of interference, if any, will depend on the desired-signal-to-interference ratio when the fire tower is communicating with other ground stations. If the tower currently enjoys good reception from ground stations, the interference from the growth system will probably be minimal.

Case 3: Aircraft over Otis AFB. PAVE PAWS interference to an aircraft equipped with a UHF/AM receiver operating on 399.9 MHz at an assumed altitude of 4,000 ft above the Otis airfield was calculated. The terms were as follows:

Table D-13

**MARGIN AT RECEIVER SOME DISTANCE FROM PAVE PAWS**
**CASE 1: UHF/AM RECEIVER**

**Source:**

| | | | | |
|---|---|---|---|---|
| Transmitter Power ($P_T$) | | | 88 | dBm |
| Antenna Gain ($G_T$) | | | 0 | dBi |
| Harmonic Suppression | | | -- | dB |
| ERP | | | 88 | dBm |

Loss:

| | | | | |
|---|---|---|---|---|
| Median Basic Transmission Loss ($L_b$) | 116 | dB | | |
| Additional Terrain Loss | 0 | dB | | |
| Foliage Loss ($L_{bf}$) | 10 | dB | | |
| | -126 | dB | | |

**Plus:**

| | | | | |
|---|---|---|---|---|
| Gain of Receiving Antenna ($G_F$) | +3 | dBi | | |
| Power at Receiver Terminals ($I_R(d)$) | | | -35 | dBm |

Receiver:

Type: UHF/AM

Distance: 6 mi (9.6 km)

Sensitivity: 1 microvolt, 50 ohms (-107 dBm)

Type Antenna: Omni, +3 dBi, h = 10 m

| | | | | |
|---|---|---|---|---|
| $R_N$ of Receiver | | | -107 | dBm |
| INR | 0 | dB | | |
| FDR | 90 | dB | | |

Margin:

| | | |
|---|---|---|
| $M(d) = R_N + INR - I_R(d) + FDR$ | +18 | dB |

$$L_b = 104 \text{ dB}$$

$$L_{bf} = 0 \text{ dB}$$

$$G_R = 0 \text{ dBi}$$

$$FDR = 90 \text{ dB.}$$

Interference is expected from both the basic and the growth systems; margin is -1 dB for the basic system and -4 dB for the growth system. Interference will be heard in the aircraft in the absence of transmission from the ground station at Otis.

However, when the ground station transmits to the aircraft (Case 3a on Table D-12, p. D-49), the desired signal is about 62 dB above receiver noise, so that a large signal-to-interference ratio (about 60 dB) will result. It is concluded that reasonably reliable UHF/AM voice communications between Otis and the aircraft will be possible, even in the presence of PAVE PAWS interference.

D.3.1.4.3.2 406.1-420 MHz Band

Case 4: Base Station, Boston. A UHF/FM base station operated on 419.325 MHz by the Department of Justice is located in Boston, 36 mi from PAVE PAWS. It is the assigned frequency closest to the low end of the PAVE PAWS band.

PAVE PAWS is not expected to cause interference to the base station for either the basic or growth systems. Margins are +19 and +16 dB, respectively.

Setting the margin at 0 dB permits determination of an estimate of the distance from the basic PAVE PAWS system at which interference to the mobile units might occur (Case 4b on Table D-12). The mobile units operating closer to Otis AFB could expect to receive interference from the lowest PAVE PAWS operating frequency (421.3 MHz) at a maximum range of about 9 mi (basic system) and about 12 mi for the growth system; however, a short pulse of interference would only occur approximately once each second and would not be a major annoyance. At very short distances from the radar the level of the interfering signal would increase in magnitude. Analysis (Case 4a on Table D-12, p. D-49) shows that a 100 W mobile transmitter probably has insufficient power to communicate reliably with the Boston base station from near Otis AFB; the predicted signal level is about 5 dB below receiver noise. This system would probably not be used for mobile-to-base communications in the Otis area.

D.3.1.4.3.3 420-450 MHz Band. This band is allocated for government-owned radars. The Government master frequency

assignment file (IRAC, 1978) also indicates the presence in this band of various experimental systems and special-purpose DOD telemetry and tracking systems. Two local radars are known to share the 420-450 MHz band with PAVE PAWS, and although analysis indicates that PAVE PAWS could probably cause interference to both, none seems to be occurring. After more than 500 hours of PAVE PAWS testing (about 75% of the time was with both faces and about half was with frequency hopping), operators of the two radars state that they have had no interference attributable to PAVE PAWS. In any case, both of these radars are directly or indirectly controlled by the Air Force, and if any interference problems do crop up, they can probably be resolved by frequency management, by operational, or by technical measures such as filtering.

Case 5: Ionospheric Radar. An ionospheric research radar is operated as a secondary user of the band by Massachusetts Institute of Technology (MIT) at Westford, Massachusetts. It is a fixed-frequency (either 440 or 440.4 MHz) UHF research radar located at the MIT Lincoln Laboratories Millstone Hill field site 77 mi from PAVE PAWS, at an azimuth of approximately 321 degrees T. The ionospheric research is conducted under contract to the National Science Foundation and the Millstone site is also supported, in part, by the Air Force.

The basic PAVE PAWS system could be expected to cause co-channel interference for this radar, for both its main beam and its sidelobes.

Case 6: Air Search Radar. An Air Force-owned AN/FPS-35 radar is operated on Montauk Point, Long Island, 84 miles from PAVE PAWS and beyond the horizon. Although tunable between 425 and 450 MHz, it is assigned to 425 MHz (IRAC, 1978). The radar is planned to be phased out of service by the Air Force during 1980.

The effects on the AN/FPS-35 are difficult to estimate, although they could be expected to cause artifacts on the operator's PPI radar display scope.

D.3.1.4.3.4 450-470 MHz Band. The 450-470 MHz band is used for land-mobile communications, principally by local governmental agencies. Communication receivers used in this band are UHF/FM receivers. A search of frequency assignments within 50 mi and 5 MHz of the highest PAVE PAWS frequency was conducted by ECAC (Moss, 1978). Table D-14 gives a summary of these assignments. The base station closest in frequency is WHDH Corporation in Newton, Massachusetts, operating on 450.15 MHz. PAVE PAWS will not cause interference to this base station because of the 51.3-mi

Table D-14

**FREQUENCY ASSIGNMENTS WITHIN 5 MHz OF PAVE PAWS**

| Operating Agency | Base City, State | Frequency (MHz) |
|---|---|---|
| WHDH Corp. | Newton, MA | 450.15 |
| Kaiser Broadcasting Co. of Mass. | Needham, MA | 450.25 |
| Franks Broadcasting Co., Inc. | E. Providence, RI | 450.35 |
| Bristol County Water Co. | Bristol, RI | 451.05 |
| New England Tel. & Tel. | Plymouth, MA | 451.5 |
| De Blois Oil Co. | Pawtucket, RI | 451.775 |
| P. D. Humphrey Co., Inc. | Tiverton, RI | 451.825 |
| J. R. Sousa & Sons Co. | Plymouth, MA | 452.125 |
| Yellow Cab of Providence R.I. | Providence, RI | 452.3 |
| Beaulahs Cab Co. | Providence, RI | 452.4 |
| Automobile Club of R.I. | Johnston, RI | 452.55 |
| Lambs Express Co., Inc. | Providence, RI | 452.65 |
| APA Transport Corp. | Rehoboth, MA | 452.7 |
| Barnstable County | Barnstable, MA | 453.7 |
| Boynton Communications | Plainsville, MA | 454.25 |

Source: ECAC Final Report (Moss, 1978).

separation. Mobile-to-base-station operation from the Otis area is highly unlikely because of the distance separation.

Case 7: Barnstable County UHF/FM Base Station. The base station nearest to PAVE PAWS is licensed to Barnstable County, at 453.7 MHz. The City of Barnstable is 15.6 mi from PAVE PAWS. The highest PAVE PAWS operating frequency, 448.7 MHz, is separated by 5 MHz from the Barnstable frequency assignment.

Calculations indicate that PAVE PAWS pulses at 448.7 MHz are very unlikely to be detected at the Barnstable base station. The margin is +7 dB for the basic PAVE PAWS system, and +4 dB for the growth system.

Barnstable County mobile units (Case 7a on Table D-12, p. D-49) operating in the vicinity of PAVE PAWS could be affected. Setting the margin at 0 dB (line 7a of Table D-12) allows solution of the equations to yield an estimate of the distance from the basic PAVE PAWS at which interference will become noticeable. The calculations indicate that mobile receivers within about 8 km (5 mi) from PAVE PAWS would experience an interference pulse occurring once per second, which could probably be corrected by a receiver squelch adjustment. Because the predicted distance from PAVE PAWS for interference to first occur is based on calculations that use rather gross assumptions for radio equipment parameters and for loss of signal power in foliage, the distance is therefore only an estimate also.

D.3.1.4.3.5 Harmonic Bands. Harmonic frequencies are generated by non-linearities. If non-linearity is present, harmonic frequencies, particularly odd harmonics (third, fifth, etc.), can be expected. In a transmitter, the ratio of the magnitude of the fundamental with respect to these harmonics is termed the harmonic suppression ratio, and is generally specified in dB for radio transmitters. Harmonic and spurious frequency suppression have been specified for PAVE PAWS to be at least 90 dB. That is, harmonic and spurious-frequency power is less than that of the fundamental frequency by a factor of 1/1,000,000,000 (90 dB). Under this specification, the ERP for harmonics and spurious signals of the basic PAVE PAWS system would not exceed -2 dBm for second and higher-order sidelobes. Actual ERP for both even-order and higher-order harmonics, such as the fourth, could be less. For purposes of analysis, an ERP of -2 dBm was assumed for all harmonics radiated from higher-order sidelobes from the basic system.

In general, the probability of interference to receivers operating at frequencies above the 420-450 MHz band is small. That low probability results from (1) the harmonic suppression specified for the radar, (2) increased basic transmission loss for the harmonic frequencies compared to the fundamental, and (3) increased attenuation effects of foliage at higher frequencies.

The following bands have been considered in our analysis of the PAVE PAWS environment.

470-806 MHz. (TV interference -- see Section D.3.1.2, p. D-19)

840-900 MHz. Receivers operating in this band could receive second harmonics from the radar. This band is allocated to

non-government land-mobile equipment. No equipment utilizing this band was identified in the Otis AFB environment.

1,260-1,350 MHz. Equipment in this band could receive third harmonics from the radar. This band is allocated for radar and radio navigation equipment. No instances of interference were predicted to occur in this frequency band from either the basic system or the growth system.

1,680-1,800 MHz. Equipment operating in this band could receive fourth harmonics from PAVE PAWS. This band is allocated for meteorological aids and government line-of-sight microwave links. One case of potential interference was identified (Coast Guard microwave).

2,100-2,250 MHz. This band is part of the common carrier line-of-sight microwave band. The fifth PAVE PAWS harmonic has the potential to interfere with receivers operating in this band. A careful examination of each possible receiver in the Otis AFB environment indicated that insufficient PAVE PAWS power would be present, even when growth system parameters were utilized. No interference was predicted to occur.

Case 8: Coast Guard Microwave Receiver. A Coast Guard microwave receiver operating at 1,700 MHz (1.7 GHz) is 3.2 mi from PAVE PAWS at an azimuth of 148 deg T. PAVE PAWS is 16 deg off the main beam of the Coast Guard's directional antenna. A path profile from the radar to the microwave site indicated that there is a line-of-sight path, although there may be intervening trees.

The power of the interfering signal, $I_R(d)$, was calculated for the PAVE PAWS fourth harmonic, assuming free space propagation loss (112 dB) and no foliage attenuation. A receiver threshold of -99.4 dBm, and antenna gain of $G_R = +5$ dBi were used. No interference-to-receiver noise ratio (INR) protection term was used. The power of the basic PAVE PAWS system is expected to be below the receiver threshold by 9 dB. For the growth system, the predicted level of the PAVE PAWS signal is below the threshold by 6 dB. That is, the predicted margins are 9 dB and 6 dB. Therefore, it seems very unlikely that interference would occur.

D.3.1.5 Airborne Systems

D.3.1.5.1 In-Band Radar Altimeters. Two aircraft radar altimeters -- the SCR-718 and the AN/APN-1 -- share the 420-to-450-MHz band with PAVE PAWS and other radar systems. Although discontinuance of the use of these altimeters has been urged, and dates for their retirement have been set and extended by OTP, they are still in use at this time. Neither is used for approaches for landing, and Tech Order 1C-135A-1 states that the SCR-718 is not to be used

within 50 miles of land. These usage restrictions greatly reduce the likelihood of PAVE PAWS' interference causing a hazardous situation. The fact that the altimeters can experience interference from in-band ground-based radars is well known.

The SCR-718 altimeter will generally be affected by PAVE PAWS when its aircraft is within radio line-of-sight of PAVE PAWS. The limit of the line-of-sight depends on the aircraft altitude and would be as far away as about 270 miles for aircraft operating at 30,000 ft. An SCR-718 altimeter may be able to still provide useful information despite some interference by PAVE PAWS; experiments would confirm or refute this. Because radar interference to this altimeter is already acknowledged to occur, operation of PAVE PAWS will not pose a unique threat.

The AN/APN-1 altimeter will be affected by PAVE PAWS when the PAVE PAWS signals are about the same order of magnitude as the altimeter's ground return. Because this altimeter's power output or antenna characteristics are not known, where it would be affected cannot be stated. However, its maximum altitude is 4,000 ft, and it would be beyond the radio horizon for PAVE PAWS (and therefore be unaffected) at about 170 miles. Again, since this altimeter already operates in the same band as other radars and is not used to determine altitude during approaches, PAVE PAWS should be no additional hazard in its use.

The general characteristics of the two altimeters are shown in Table D-15. The SCR-718 type is used in some C-97, C-118, C-121, C-130, C-131, and C-135 aircraft; the AN/APN-1 type is used in some A-3, C-117, C-118, C-119, and P-2 aircraft.

D.3.1.5.1.1 The SCR-718 Pulse Radar Altimeter. The operating frequency for the SCR-718 is 440 MHz, and the transmitter power depends on the altitude range in use (See Table D-15) Calculations show that distance alone is not sufficient to attenuate the PAVE PAWS signal to levels that will not affect the SCR-718. It appears that the only way for the SCR-718 radar altimeter to be totally unaffected by PAVE PAWS is for it to be used beyond the radar horizon.

Generally, when in radio-line-of-sight of PAVE PAWS, an aircraft would be exposed to PAVE PAWS higher-order sidelobes. As discussed in Section D.2.6.2, p. D-14, the aircraft would be illuminated for about 18% of the time. However, because of the PAVE PAWS frequency hopping, the SCR-718 would not be susceptible to all PAVE PAWS pulses. The SCR-718's receiver response curve suggests that although it is illuminated about 18% of the time, it would be affected only about 9% of the time or less. Whether this adversely affects the function of the altimeter would have to be determined, probably by experimentation.

Table D-15

CHARACTERISTICS OF TWO RADAR ALTIMETERS

| Nomenclature | SCR-718 | | AN/APN-1 | |
|---|---|---|---|---|
| Frequency | 440 MHz | | Varies sinusoidally, 120-Hz rate | |
| Emission Type | Pulse (0.3 microseconds) | | FM-CW | |
| Altitude range (ft) | 1-5,000 | 0-50,000 | 0-400 | 0-4,000 |
| Pulse power (dBm) | 38.5 | 37 | not given | |
| PRF (pps) | 98,350 | 9,835 | not applicable | |
| Frequency range (MHz) | not applicable | | 420-460 | 443-447 |
| Sensitivity threshold (dBm) | -70 | -70 | -87 | -87 |

Source: Siemen, 1977.

An SCR-718 illuminated by a strong PAVE PAWS signal may still be usable. The display on the SCR-718 radar altimeter is a cathode ray tube (CRT) on which a spot continually moves in a circle. The spot takes about 10 microseconds for a revolution when the altimeter is in the low-altitude range and about 100 microseconds when in the high-altitude range. The return pulse causes the trace to deflect radially outward, placing a bump on the circle at some position. Numbers superimposed on the CRT face allow the location of the bump to be interpreted as aircraft altitude. The angle covered by the bump is dictated by the duration of the received signal (the transmitted pulse is 0.3 microseconds long and so the bump is small). Reception of a longer pulse, such as a PAVE PAWS long-range surveillance pulse (8 or 5 ms) would cause deflection of the entire circular trace for many revolutions of the spot. The persistence of the CRT face may permit the desired trace to be seen when it occurs, despite the whole-circle deflection occurring part of the time. Experiments would have to be performed to determine whether this is so.

D.3.1.5.1.2 The AN/APN-1 FM-CW Radar Altimeter. This FM-CW altimeter transmits continually, varying its frequency in a sinusoidal manner (at a 120-Hz rate) between the frequency limits

shown in Table D-15. The frequency of the return from the ground is the frequency that was transmitted a brief time before (i.e., the duration corresponding to the signal's round trip from plane to ground to plane). The radar mixes this return signal with the frequency currently being transmitted. The difference frequency is then amplified in an audio-frequency amplifier and limited, to obtain square waves at the difference frequency. These square waves are converted to a dc voltage proportional to their frequency and thus, proportional to the altitude of the aircraft.

A strong interfering signal (such as from PAVE PAWS) can enter the receiver to mix with the frequency being transmitted, and if their frequency difference is within the pass-band of the audio amplifier, the square waves from that frequency will be converted to a dc value to drive the altimeter's meter. If the interfering frequency is present long enough, the meter response will be determined totally by the interfering frequency. If the interfering frequency is present only for a short while, the meter will simply read inaccurately.

In the low-altitude range, the frequency of the altimeter swings between 420 and 460 MHz; in the high-altitude range it swings between 443 and 447 MHz. Therefore, the frequency is likely to swing through a PAVE PAWS signal, which would cause interference. In the high-altitude range, the altimeter would be susceptible to interference only from the PAVE PAWS signals inside roughly the 443-to-447-MHz band, and so only 5 of the 24 PAVE PAWS frequencies seem likely to pose any problem in that range. In the low-altitude range, the altimeter would be susceptible to all 24 of the PAVE PAWS frequencies, but the altimeter's 40-MHz frequency swing also takes it 10 MHz above the PAVE PAWS band. Since it is outside the PAVE PAWS band for 25% of the time, only the other 75% is of concern.

Interference will occur only when the frequencies of the altimeter signal and the PAVE PAWS signal are close enough to permit their difference frequency (delta f) to pass through the altimeter's audio frequency amplifier. Siemen (1977) points out that during the interference periods, the difference frequency sweeps from high values of delta f through zero frequency and back through high values of delta f. While under the control of the PAVE PAWS signal then, the altimeter will attempt to read high (since high delta f also implies high altitude). The extent to which the meter can be dragged high depends on the audio amplifier's rejection of increasingly high frequencies and on the duration of the interference each time it occurs.

The metering system operates such that it responds very rapidly to the high delta f of the interfering signal, but then relaxes so slowly when the interference is removed that it takes about a half-second to recover.

Siemen (1977) states that an aircraft will receive sufficient energy so that the interfering signal predominates at the output of the AN/APN-1 limiter when the interfering signal is 10 dB above the desired signal. From the discussion on average pulse rates from PAVE PAWS higher-order sidelobes (Section D.2.6.2, p. D-14), about 16.6 long-range surveillance pulses and about 28.3 short-range surveillance pulses per second can be expected. The number and types of track pulses cannot be predicted because they depend on the targets being tracked.

Apparently, a PAVE PAWS signal 10 dB above the altimeter's own return signal would control the altimeter. However, the ECAC analysis (Siemen, 1977) provides no information on the level of the altimeter's own input signal other than to say that the threshold level of the AN/APN-1 is -87 dBm. Without calculations of received power levels or of the levels of the PAVE PAWS signal that would lead to degrading effects, the distance from PAVE PAWS that an aircraft equipped with the AN/APN-1 must be to operate without interference cannot be predicted. Siemen says that approximately 190 miles would be sufficient when the aircraft is at 4,000 ft (the maximum altitude for this altimeter). This is well beyond the radio horizon, which is at about 120 miles for an aircraft at 4,000 ft.

D.3.1.5.2 <u>Other Aids to Navigation</u>. Radio-operated aids to air navigation, maintained throughout the United States, consist of ground stations and equipment in the aircraft. Ground-stations have been set up in the vicinity of Cape Cod, and aircraft using them will be illuminated by PAVE PAWS. Nevertheless, effects at ranges greater than a mile or so from PAVE PAWS do not appear likely, based on the meager measurements available.

D.3.1.5.2.1 <u>TACAN and DME</u>. In this extensively-used system, aircraft use radio transmissions between themselves and a ground station to determine two items of information: the distance to the ground station, and the bearing to it. The distance measuring equipment (DME) methods and frequencies are identical for military and civilian aircraft, and both use the same ground stations. Aircraft using the military equipment, Tactical Air Navigation System (TACAN), can extract both distance and bearing from a TACAN ground station. Civilian aircraft use the TACAN ground station with their DME systems to measure distance. They obtain bearings from a VHF Omnirange (VOR) colocated with the TACAN beacon. Such a colocated VOR/TACAN system is called a VORTAC.

The VOR system operates in the 108 to 118 MHz band (just above the FM broadcast band and far below the PAVE PAWS band). TACAN and DME operate in the band from 960 to 1,215 MHz. The VORTAC or TACAN stations in the general vicinity of PAVE PAWS are listed in Table D-16. Second and third harmonics of PAVE PAWS are in the

Table D-16

VORTAC/DME STATIONS IN THE PAVE PAWS AREA

| Call Letters | Location | Beacon Frequencies (MHz) Transmit | Receive | Spurious Response Frequencies[a] (MHz) | |
|---|---|---|---|---|---|
| HYA | N.E. of Hyannis Airport | 1,181 | 1,118 | 459.8, 434.6, 485.0, 459.8 | + |
| FMH | Otis AFB | 1,192 | 1,129 | 464.2, 439.0, 489.4, 464.2 | + |
| BOS | Near Boston | 1,161 | 1,098 | 451.8, 426.6, 477.0, 451.8 | + |
| HTM | Whitman | 988 | 1,051 | 437.0, 411.8, 411.8, 386.6 | + |
| ACK | Nantucket Island | ,211 | 1,148 | 471.8, 446.6, 497.0, 491.8 | + |
| MVY | Martha's Vineyard | 980 | 1,043 | 429.8, 404.6, 404.6, 379.4 | + |
| PVD | Near Providence | 1,190 | 1,127 | 463.4, 438.2, 488.6, 463.4 | + |

[a] $F_{sp} = \frac{1}{q}\,\mathrm{abs}(pF_{LO} \pm F_{IF})$, where p = 2, q = 5.

bands 840 to 900 MHz and 1,260 to 1,350 MHz, respectively, so they can be ruled out as an interference mechanism to TACAN. Moss (1977) mentions that spurious responses involving the second harmonic of the TACAN receiver's local oscillator and the fifth harmonic of the PAVE PAWS signal are possible. That type of spurious response will occur only for the airborne receivers. The ++ particular frequencies are those underlined in Table D-16. (The spurious response frequencies not underlined are outside the PAVE PAWS band.) Even so, interference is not expected, for the following reasons. First, only a single one of the 24 PAVE PAWS frequencies would be involved, and a pulse at that frequency would illuminate the aircraft only about once every 33 seconds. The TACAN receiver is designed to ignore pulses that are not ground-station returns of its own downlink pulses. Thus, an occasional spurious pulse should present no problem. Finally, spurious response rejection in TACAN receivers is at least 92 dB to frequencies in the 420-to-450-MHz band.

Some tests have been made on two airborne units, one a military TACAN system and the other a DME-70 for military or general avaiation. High-power effects were not noted on either unit at the maximum available power density levels in the 420 to 450 MHz range. These maximum levels were 37 dBm/m$^2$ for the TACAN receiver and 43 dBm/m$^2$ for the DME receiver (500 and 2,000 microwatts/cm$^2$, respectively). Although such pulse power densities are not reached even by the first sidelobe outside the 1,000-ft exclusion fence (see Figure D-13), they can be reached within the main beam at distances of about 5 miles or less. As the susceptibility thresholds are greater than the power density numbers mentioned above, the aircraft may be able to come closer than 5 miles with no effect. When in the main-beam surveillance volume, an aircraft would be illuminated by the main beam at a rate of about once every 1.4 seconds. (Surveillance pulses account for the once-per-1.4 sec rate; PAVE PAWS will not track aircraft.) If affected only so infrequently, the TACAN/DME airborne interrogator may only momentarily lose lock, and switch from its tracking mode of operation to its searching mode. +

D.3.1.5.2.2 Miscellaneous Systems. Measurements of high-power effects have been made on other air-navigation aids. The pertinent results are given in Table D-17, p. D-64. The units were tested with desired-signal levels "representing either realistic maximum use distances or design maximum distances for the receivers." The susceptibility thresholds quoted are all for antenna-coupled interference, based on lab measurements and an assumption of the gain of the system's antenna to the interfering signal. The susceptibility levels will probably increase under most circumstances, because the systems will be receiving higher levels of desired signals.

Even so, after placing the susceptibility thresholds of Table D-17 on the power density plot of Figure D-13, it does not appear that airborne nagivation systems of these types will suffer interfering effects from PAVE PAWS. No information was given on the spurious response frequencies, but, because of the nature of spurious responses, not all of the PAVE PAWS frequencies would be involved.

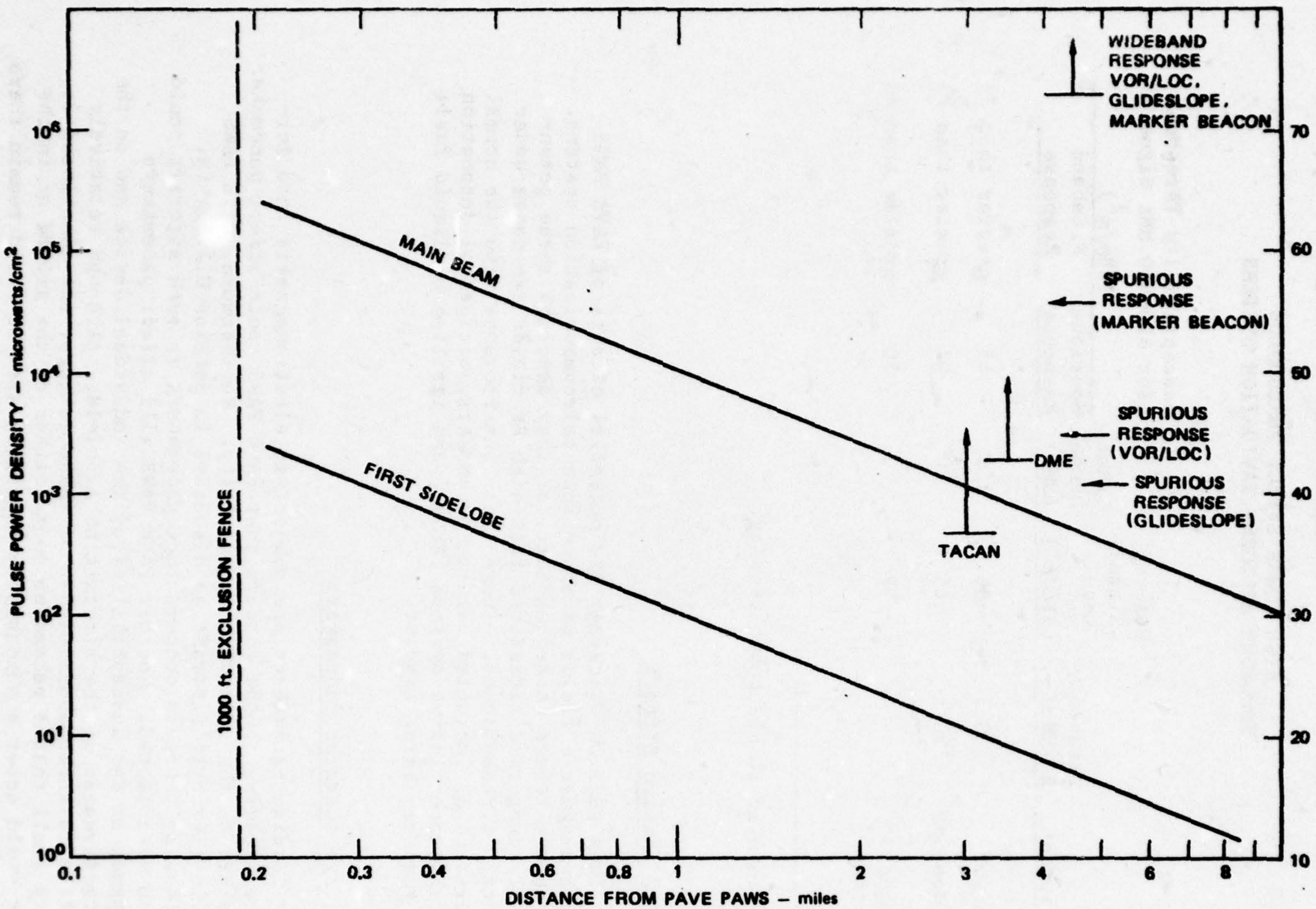


FIGURE D-13. SUSCEPTIBILITY THRESHOLDS (AND LOWER BOUNDS) FOR SOME AIRBORNE ELECTRONIC SYSTEMS (PAVE PAWS BASIC SYSTEM)

Table D-17

HIGH POWER EFFECT THRESHOLDS
FOR SOME AIRBORNE NAVIGATION SYSTEMS

| Equipment | Frequency (MHz) | Desired Signal Level (dBm/m$^2$) | Slant Range (NMi) | Susceptibility Threshold (for 420-450 MHz Signals) (dBm/m$^2$) Spurious Response | Wideband Response |
|---|---|---|---|---|---|
| VOR/LOC | 108.1 | -66 | 150 | 45 | greater than 73[a] |
| Glideslope | 330 | -65 | 20 | 41 | greater than 73 |
| Marker Beacon | | -49 | 2 | 56 | greater than 73 |

[a]Maximum available power density.

### D.3.2 Hazard Effects

This section discusses the potential effects of PAVE PAWS electromagnetic fields on other than telecommunication systems. These are termed hazard effects, as they describe three potentially dangerous situations that high RF fields can cause under certain circumstances. These are: interference with the normal operation of implanted cardiac pacemakers, accidental detonation of electroexplosive devices (EEDs), and ignition of liquid fuels as they are being handled.

#### D.3.2.1 Cardiac Pacemakers

Cardiac pacemakers are subject to electromagnetic interference, leading to the concern that PAVE PAWS could affect pacemaker wearers on the ground in its vicinity. Furthermore, PAVE PAWS will illuminate aircraft as discussed in Section D.2.6.1 (p. D-14), so there is concern that pacemakers in such aircraft could also be affected. Whether PAVE PAWS will affect pacemakers depends on the susceptibility of the individual device and on the effectiveness of the aircraft as a shield. Although relatively little is known about either of these factors, the likelihood is very small that a pacemaker owner either on the ground or in the air would enter a potentially dangerous area or could remain there long enough to be affected.

D.3.2.1.1 Background. The heart can be considered to be an electrically operated pump. It is a set of muscles that contracts rhythmically in response to a periodic electrical impulse that originates naturally in a certain portion of the cardiac tissue. Some people who suffer impaired operation of the natural pacemaker or of the conducting paths in the cardiac tissue, rely on an artificial pacemaker, which supplies the electrical signal to make the heart beat when it should. From 100,000 to 300,000 people in the United States have pacemakers.

Four general types of cardiac pacemakers are employed: asynchronous (or fixed-rate), P-wave synchronous, R-wave synchronous, and R-wave inhibited. Because the last three types sense cardiac electrical activity, they may be subject to effects from external electromagnetic fields. The R-wave inhibited pacemaker only operates on demand (i.e., when the heart requires it). It senses the electrical signal of the main pumping action of the heart. If that fails to occur when it should, the pacemaker supplies the signal to trigger the heart's action. The R-wave inhibited pacemaker is the most common type; currently, 80 to 90% of pacemakers in use are of that type. R-wave inhibited pacemakers are generally more susceptible to electromagnetic interference (EMI) than the other types are.

Pacemakers do not necessarily fail permanently when exposed to strong RF fields; instead, they may exhibit one of four types of dysfunction:

- Inhibition -- the pacemaker does not generate the required pulses.
- Irregular Pulses -- the pacemaker does not maintain a steady rhythm.
- Excessive or Insufficient Pulses -- the pacemaker rate exceeds 150 pulses per minute (ppm) or is less than 50 ppm.
- Reversion -- the pacemaker reverts to a benign fixed rate. A synchronous pacemaker is designed to respond to RF by becoming, for the time being, an asynchronous pacemaker. Reversion is not always considered a form of dysfunction, but neither is it altogether desirable.

D.3.2.1.2 Susceptibility to Pulsed RF Fields. The susceptibility of pacemakers to RF fields at or near 450 MHz has been measured by several researchers. Denny et al. (1977) state that pacemakers have become noticeably less susceptible in recent years. They describe the results of measurements of susceptibility thresholds for pacemakers in saline solution. Their published results include old and new pacemakers, as well as prototypes that may not

have gone into production (Denny and Toler, private communication, September 1978). Schlentz et al. (1976) have shown that results of tests in saline are entirely equivalent, at 450 MHz, to tests of implanted pacemakers. In either situation, the corresponding field strengths are defined and measured in air, just outside the body or saline solution. + +

A pacemaker wearer who approaches PAVE PAWS on the ground cannot be exposed to the fields from the main beam. At the close distances of interest, only the higher-order sidelobes will illuminate the ground. The long-range surveillance resources occur at an average rate of about 5.5 pulse clusters (pulse pairs and triplets) per second. Tracking pulses would occur almost randomly in time but may be clustered. How the pacemaker would interpret this "PRF" is uncertain, both because PAVE PAWS does not have a specific deterministic PRF and because it is uncertain whether a pacemaker's circuitry would "see" the pulse clusters within a resource as individual pulses or would see each cluster as if it were one pulse (approximately 16 ms long in the case of a long-range surveillance resource). Assuming the latter, less favorable case, the pacemaker would probably interpret the PRF to be less than 10 pulses per second (pps).

A pacemaker owner in an aircraft could be subjected to the high-order sidelobe pulses and possibly to the energy of the main beam or the first sidelobe as well. If the aircraft were in the volume of the main surveillance beam (see Figure D-14, p. D-69), the pacemaker owner would be illuminated with a pulse from the main beam at least once every 1.4 seconds (or at a rate of about 0.71 pps). This includes only surveillance pulses, because PAVE PAWS does not track aircraft.

According to Denny et al., at low PRFs (less than 10 pps) an R-wave inhibited pacemaker is likely to misinterpret the pulses as the heart's electrical activity and become inhibited. At higher PRFs, it is more likely to revert to asynchronous operation. Long term inhibition (for durations greater than about five normal heartbeats) may constitute a health hazard for some owners, whereas reversion is less serious.

Although pulse-susceptibility data are available in the literature (Denny et al., 1977; Mitchell et al., date unknown; Mitchell and Hurt, 1976), this information must be interpreted with caution. For example, the published version of the work of Denny et al. (1977) does not mention that their plots of susceptibility thresholds were developed using many prototype or developmental pacemakers, some of which did not go into production as tested because of the low susceptibility thresholds shown in the paper. Thus, although that paper shows the results of many tests, the data does not necessarily represent the susceptibility thresholds of the pacemakers that have actually been manufactured and implanted in cardiac patients.

The susceptibility levels published by Mitchell and Hurt (1976), which range from 4 V/m to more than 260 V/m at 450 MHz, with ten 20-ms pps, represent a smaller sample; however, the pacemakers referred to are actual (serial-numbered or model-numbered) units. That 1976 report states that the susceptibility levels presented "are believed most representative of the current state of technology." The report also states that "if pacemakers were designed and tested to be compatible with the minimum E-field level, viz 200 V/m, associated with the unrestricted 10 $mW/cm^2$ (10,000 $microwatts/cm^2$) personnel exposure level, potential EMI situations would be substantially reduced or effectively eliminated."

A 200-V/m testing level is described in a draft standard prepared by the Association for the Advancement of Medical Instrumentation (AAMI) for the Food and Drug Administration. Testing is to be done at, but not necessarily above, 200 V/m within 50 MHz of 450 MHz and at pulse repetition frequencies of 125% $\pm$ 10% of the basic rate of the pacemaker.

Both Mitchell and Denny suggest that the manufacturers are certainly trying to meet and may now be meeting the 200-V/m level in their newer models (private conversations, September 1978). Some preliminary data from measurements by Mitchell in 1977 indicates that many are not susceptible to levels as high as 330 V/m. Denny stated that the threshold for most of the newly released pacemakers is above 300 V/m. However, he also stated that manufacturers' catalogs show that some of the unshielded and unfiltered, and therefore highly susceptible, pacemakers are still being offered for implantation. Talks with manufacturers confirm this.

Manufacturers contacted state that their newer pacemakers meet the draft AAMI standard, and one manufacturer said that the manual for a particular model states that it has been tested to 295 V/m. However, many older pacemakers are still in use, and so the actual susceptibility thresholds of the pacemakers currently in use remain unknown. Complete information directly relevant to PAVE PAWS requires knowledge of the mix of the pacemakers now in operation, by manufacturer and by model; and susceptibility of each type of unit to the specific pulse width, PRF, and frequency hopping characteristics of PAVE PAWS. This is nearly impossible as typically the pacemaker manufacturers do not provide this desired 450-MHz susceptibility information on their specification sheets. Moreover, the situation is in a state of flux. An entirely new pacemaker must be implanted in an individual when the battery becomes exhausted, and so the physician has an opportunity, but not a mandate, to implant a pacemaker less susceptible to EMI. When mercury cells were the only ones used, replacement was necessary about every 2 to 3 years; lithium iodide batteries last 4 or 5 years or more and are now the type more frequently used. (An atomic power source, with a life of 15-20 years, is very rarely

used. It is very expensive and is used only with very young patients.) Thus, accurate EMI characteristics of the pacemaker population cannot be specified.

D.3.2.1.3 Susceptibility to PAVE PAWS. Figure D-14 compares the suggested 200-V/m susceptibility threshold with predicted PAVE PAWS field strength. Pacemakers with that susceptibility will be affected only if the owner is in the main-beam volume and within 1 mile of the basic system or within 2 miles of the growth system. The device would not be affected by any of the sidelobes.

To be illuminated by the main beam at all, the pacemaker's owner must be airborne; a pacemaker owner on the ground is not jeopardized, providing his pacemaker meets the suggested 200-V/m minimum susceptibility level. Further, for the owner to be affected, the airborne pacemaker must remain in the main-beam volume for a period of time. The School of Aerospace Medicine advises that five successive beats of the pacemaker must be interfered with to create a significant effect. At a rate of 72 heartbeats per minute, 5 beats requires about 4 seconds. PAVE PAWS will not track aircraft, so tracking pulses will not be a threat to the pacemaker owner.

It will be very difficult for an aircraft to remain within the volume probed by the PAVE PAWS main beam in the surveillance mode long enough for a pacemaker owner to be affected. The volume probed by the PAVE PAWS main beam in the surveillance mode is defined by the beam elevation angle and its beamwidth and by the 240 deg azimuthal coverage of PAVE PAWS. The beam elevation is normally 3 deg and the beamwidth, for the basic system, is 2.2 deg (the growth option beamwidth is 1.5 deg). Figure D-15 shows a plan view and a cross-section of that volume within a mile of PAVE PAWS; this is the volume within which a pacemaker with a susceptibility threshold of 200 V/m might be affected. (The cross-section view shown here exaggerates the thickness of the volume, which is only about 200 ft thick at a mile.) This volume is almost totally within the restricted area R-4101 that includes essentially the northern half of Otis AFB. The area is restricted from ground level to 9,000 ft between 0600 and 1800 daily. Any aircraft flying more than a mile away or more than about 380 ft above PAVE PAWS will never be within the volume where the field exceeds 200 V/m. No established flight paths pass through the volume. Therefore, pilots regarding the restricted area and following FAA recommendations against flying within 500 ft of persons or structures will not place their aircraft within this volume.

Pilots who do not follow these rules could perform maneuvers that would bring their aircraft into the volume for various lengths of time, depending on the flight path and the aircraft speed. A straight and level flight directly over PAVE PAWS (see flight path A on Figure D-15) would bring the aircraft within the

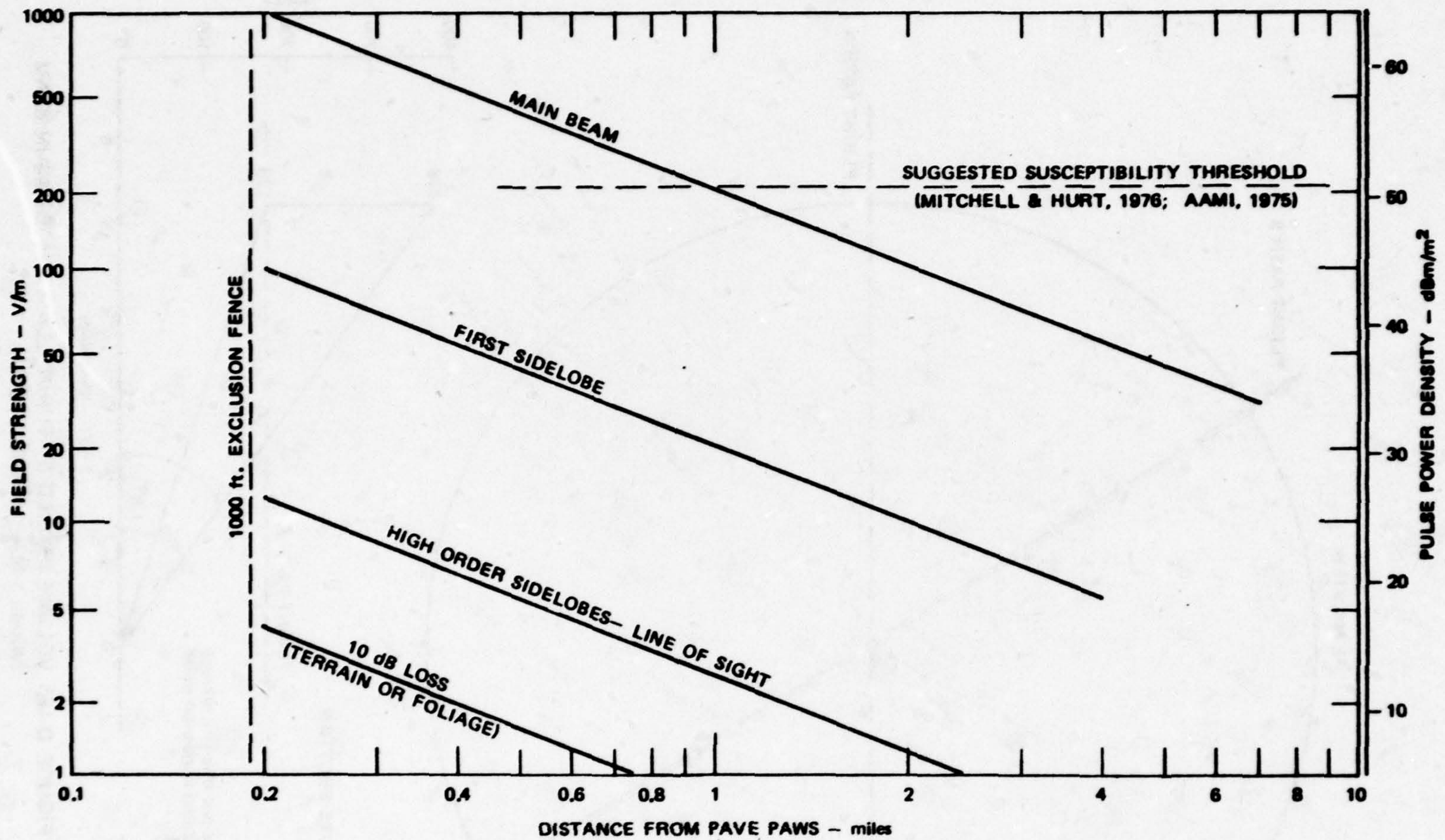


FIGURE D-14. EFFECTS OF PAVE PAWS ON PACEMAKERS, BASIC SYSTEM

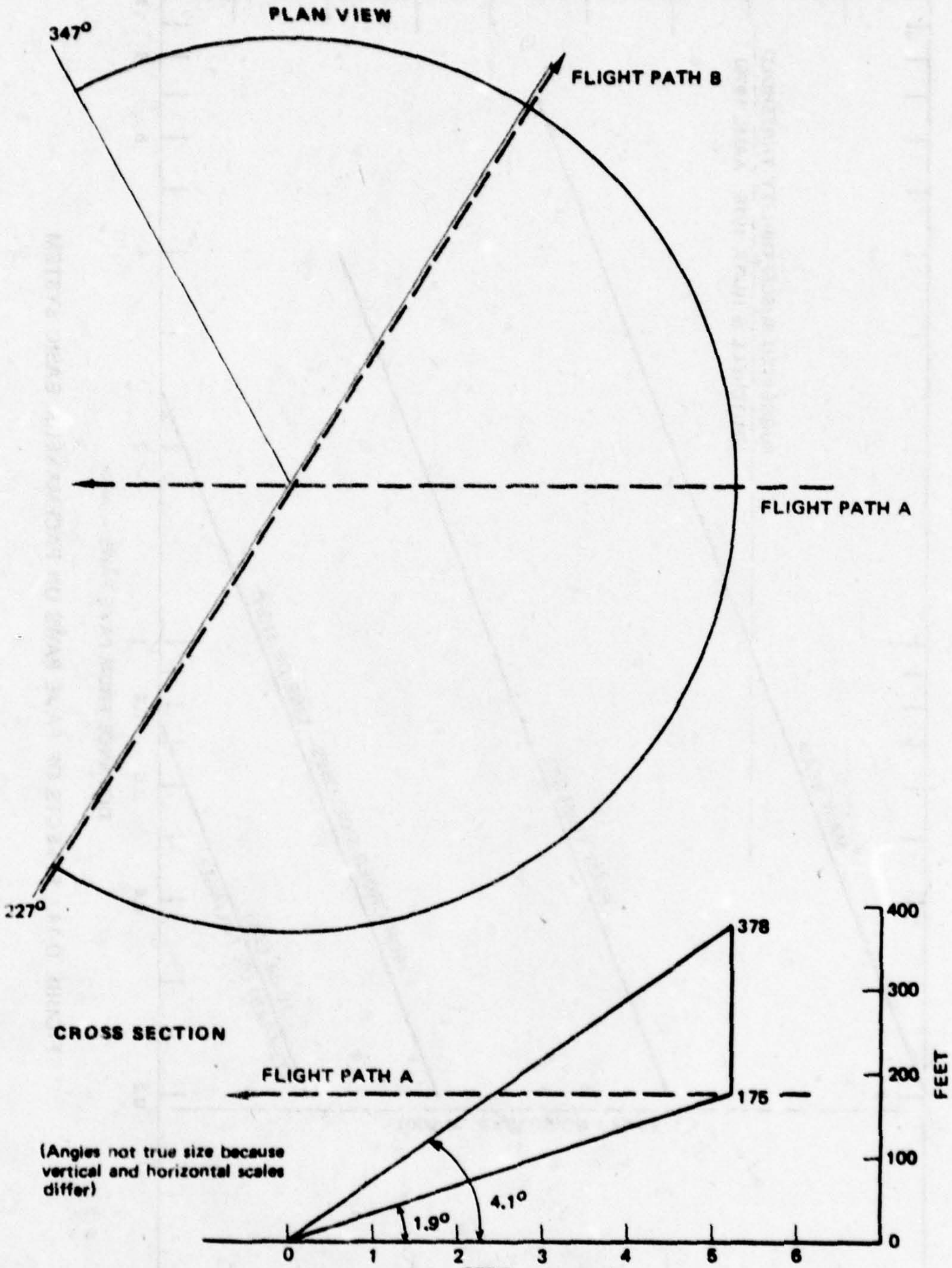


FIGURE D-15. VOLUME PROBED BY SURVEILLANCE-MODE MAIN BEAM (Within 1 Mile), BASIC SYSTEM

volume for a duration that depends on the aircraft altitude. At an altitude of about 175 ft, the aircraft would enter the volume at a distance of one mile, and emerge above it at a distance of about 2300 ft (higher or lower altitudes would cause less exposure, as the cross-section of Figure D-15 indicates). The duration would be $t = 2030/r$ seconds where r is the aircraft speed in miles per hour (about 20 seconds for a slow, 100 mph aircraft). For flight path B at the same 175-ft altitude, the same slow aircraft would be within the volume for two 20-second periods, separated by a period of about 32 seconds as it passed over the radar.

Various other flight paths, such as those passing near, but not over, the radar could be discussed. All, however, would demonstrate the same situation: it requires very imprudent flying and disregard of basic flight safety to bring an aircraft within the volume where the field strength exceeds 200 V/m.

If the aircraft provides any shielding at all for the pacemaker wearer, the volume of concern will be greatly decreased. For a very moderate shielding of 3 dB, the radius defining the outer range of the volume will shrink by a factor of 1.4 and the volume + would then be totally within the present restricted area. Then, + an aircraft will have to fly lower to enter the volume, and it will not be able to remain in it for so long.

For the growth option, the radius of concern becomes 2 miles, but the beam is narrower, and, at that distance, it extends from a height of about 415 ft to about 690 ft. A slow aircraft overflying the growth-option PAVE PAWS at a prudent 500-ft altitude would be within the volume for two 20-second periods separated by about 100 seconds, as the aircraft passes over.

If a pacemaker in the surveillance volume were to be affected by each PAVE PAWS pulse, it would be inhibitied for portions of the durations just indicated. The main-beam "PRF" is about 0.7 pps (see Section D.2.6.1, p. D-14), and short and long surveillance pulses are emitted in a pseudorandom sequence. If a demand pacemaker were to interpret each PAVE PAWS pulse it receives as cardiac R-wave activity, it would be inhibited for a period of about 900 ms after each pulse. Multiplying 0.7 pps by 0.9 seconds of inhibition per pulse indicates that the pacemaker would be inhibited by the radar about 63% of the time it is in the surveillance volume within 1 mile of PAVE PAWS. If the pacemaker reacts only to the long pulses of the long-range surveillance, it would still be inhibited part of the time (Denny et al. indicate that susceptibility increases with pulse length). The average PRF of these long pulses is about 0.24 pulses per second, implying inhibition about 21% of the time the aircraft is in the surveillance volume within 1 mile of PAVE PAWS.

However, various circumstances make it very unlikely that a pacemaker will be affected by each PAVE PAWS pulse even within the

surveillance volume where the field exceeds 200 V/m. For one thing, susceptibility testing is done with the pacemaker's catheter extended and aligned for maximum coupling with the electromagnetic field. An implanted pacemaker's catheter is neither extended nor is it optimally aligned with the field, a circumstance that improves (decreases) the susceptibility of an implanted pacemaker. Normal minor shifts in body attitude relative to an impinging electromagnetic field can also cause great changes in pacemaker susceptibility. Also, whatever shielding is afforded by the aircraft (which will depend on the attitude of the aircraft relative to the beam, on the aircraft type, on the window size, and on many other variables) will decrease the size of the volume of concern. A small volume will be more difficult for the careless flyer to enter and the duration he can spend in it will also be reduced. Thus, even if a flyer were to carelessly enter the volume where the field exceeds 200 V/m, other circumstances would still make extended durations of pacemaker dysfunction unlikely, so that harmful effects on the pacemaker's owner are unlikely.

### D.3.2.2 Fuel Handling

The military has long been concerned over the possibility that high-powered radars (such as those on an aircraft carrier) could ignite volatile fuels as they are transferred. Ignition would result if the high RF fields caused a spark across a gap in a fuel-air mixture having certain proportions. Experiments have determined the dc spark energy required to ignite fuel, and "the amount of RF voltage required to break down a similar gap is unknown but is believed, until proven otherwise, to be approximately the same as the dc-voltage value." For fuel handling near a radar, "a peak power density of 5 watts/cm$^2$ (5,000,000 microwatts/cm$^2$) or less can be considered safe" (A.F. Technical Manual, T.O. 31Z-10-4).

Even for the PAVE PAWS growth system, the pulse power density at the 1,000-ft exclusion fence for the high-order sidelobes is only about 5,700 microwatts/cm$^2$, about one-tenth of one percent of the maximum safe power density level. At 100 ft in front of the growth system, the pulse power density is about 51,600 microwatts/cm$^2$, about one percent of the maximum safe level.

PAVE PAWS will not pose a hazard to fuel handling operations.

### D.3.2.3 Electro-Explosive Devices (EEDs)

#### D.3.2.3.1 Description

Electro-explosive devices (EEDs) are used to activate secondary explosive charges, to ignite propellant systems, and to actuate electro-explosive switches. There are four basic types of

EEDs. The types, actuation mechanisms, and uses are as follows (Hovan, 1978):

- Exploding bridgewire -- Requires a high-energy capacitive discharge pulse to explode bridgewire.

- Normal bridgewire -- An explosive mix is glued to the bridgewire. Electrical current heats the bridgewire, detonating the adhesive primer.

- Composition mix -- Uses conductive explosive mix. Current passes through the mix, igniting it.

- Carbon bridge type -- Used internally in 3 or 4 weapons systems and in 20-mm cartridge primers. This type of EED, when used in 20-mm cartridge primers, is the type most sensitive to RF fields. It is also sensitive to static electricity. The hazard for the 20 mm primer comes from ground crews touching the base primer during loading. If RF energy (or static electricity) is present, personnel touching the primer can couple energy into the EED. Special handling-safety precautions exist for 20-mm ammunition.

D.3.2.3.2 Other Safety Standards. Air Force safety standards for EEDs apply to the manufacture, testing, storage, transport, loading, and operational use of systems containing EEDs. The standards have been established to minimize the accidental detonation of weapons by environmental causes or by personnel. In addition to the electromagnetic radiation hazards to EEDs, AF Regulation 127-100 (31 March 1978) considers various electrical hazards, including location of power lines and electrical equipment, lighting, static electricity and grounding, and lightning protection.

D.3.2.3.3 Explosive Safety Standards for EEDs. Safe exposure levels to RF fields for EEDs are contained in AF Regulation 127-100. The criteria given in this regulation are given for average power density ($W/m^2$) and apply to three of the classes of EEDs just described. (The 20-mm cartridge primers are treated as if they are sensitive to pulse power. The safe power density level given in the regulation is keyed to the storage and exposure conditions of the EED and also to the frequency of the electromagnetic field. EEDs stored in metallic containers are less susceptible to the fields than are those directly exposed to the RF environment.

Safe power density exposure limits for EEDs to a 420-MHz electromagnetic field are summarized in Table D-18. (Only the 20-mm cartridges consider pulse power.) Because of the 18% duty cycle, average power density for higher-order sidelobes of PAVE PAWS is 7.4 dB (5.5 times) lower than pulse power density.

Table D-18

SAFE EXPOSURE LIMITS FOR EEDs AT 420 MHz

| Exposure or Storage Condition of EED | Average Power Density $W/m^2$ | Average Power Density Microwatts/$cm^2$ |
|---|---|---|
| **Exposed Condition** | | |
| (1) EEDs in storage or transport, in non-metallic containers, leads shorted | 0.75 | 75 |
| (2) EEDs in exposed condition (20-mm handling criteria) | 0.75[a] | 75[a] |
| **Aircraft Taxiing** | | |
| (3) Aircraft taxiing with externally-loaded weapons | 6.63 | 663 |
| **Storage Inflight** | | |
| (4) EEDs stored and transported in metallic containers | 100.0 | 10,000 |
| (5) Shipment of EEDs inside cargo aircraft | 100.0 | 10,000 |
| (6) In-flight aircraft with externally-loaded weapons | 100.0 | 10,000 |

[a]This limit only is pulse power density rather than average.

Source: Explosive Safety Standards AF Regulation 127-100 (March 1978).

Finally, even if the safe power density limit is exceeded, the EEDs will not necessarily fire. That limit is established to be significantly below the firing threshold of the device, although no data on this safety factor was located. Good engineering and safety practices, however, would dictate a minimum safety threshold several orders of magnitude below the firing threshold.

Manufacturers of weapons systems are required to design and demonstrate a no-fire current condition on firing leads of weapons systems (MIL-STD 1512). They are also required to demonstrate a no-fire current condition of 1 amp on the closed firing circuit for 5 minutes (or current produced by 1 W into the firing circuit load -- whichever is larger). Electromagnetic fields required to couple this level of current into a firing circuit are very large.

D.3.2.3.4 PAVE PAWS Power Densities. The average power density from PAVE PAWS (Tables A-4 and A-5, pp. A-27 and A-29) can be compared with the safe exposure limits for EEDs. At ground level none of the average power density exposure limits of Table D-18 are exceeded by the basic PAVE PAWS system outside the 1,000-ft exclusion fence even if PAVE PAWS is operating at its 25% duty cycle. The pulse power density criteria (for handling 20-mm cartridges) is exceeded by the basic PAVE PAWS system only inside a distance of about 1,100 ft. For the growth system, the average (25% duty cycle) power density at ground level is upper bounded by 1,400 microwatts/cm$^2$ at the 1,000-ft exclusion fence and, by about 1,400 ft, has dropped to not more than 32 microwatts/cm$^2$, even in the overlap sector. Thus, even aircraft taxiing with externally loaded weapons, and exposed EEDs, would be in no danger this close. (In fact, the Otis AFB runways are several miles away and no roads pass as closely as 1,400 ft.) The 20-mm cartridge-handling criteria is satisfied outside about 1,500 ft for the growth system. Table D-19 lists appropriate separation distances.

Aircraft in flight would be illuminated by the main beam and the sidelobes. The average power density for the main beam (from Section D.2.6.3, page D-15) is

$$P_r(d_f) = 125 - 20 \log d_f - D \quad \text{dBm/m}^2\text{, where}$$

$d_f$ = distance from PAVE PAWS in feet, and

D = "duty cycle": 10 log (pulse on-time/total time).

In the surveillance mode, an 8-ms or 5-ms long-range surveillance pulse is transmitted toward the airborne target about every 4 seconds, and a 0.3-ms short-range surveillance pulse about every 2.1 seconds. Aircraft are not tracked. Considering both pulse types, the effective duty cycle (as seen by the aircraft) is then

**Table D-19**

**SEPARATION DISTANCE FROM PAVE PAWS FOR EEDs ILLUMINATED BY HIGHER-ORDER SIDELOBES**

| EED Exposure | Criteria, Average Power Density (Microwatts/cm$^2$)[a] | Basic System (ft) | Growth System (ft) |
|---|---|---|---|
| Exposed Condition | 75 | less than 1,000 | less than 1,400 |
| Aircraft Taxiing | 663 | less than 1,000 | less than 1,000 |
| Storage/In-flight | 10,000 | less than 1,000 | less than 1,000 |
| Handling 20-mm Cartridges | 75 (pulse) | about 1,100 | about 1,500 |

[a]AF Regulation 127-100.

about D = -26.8 dB, and so the average power density from the main beam is about

$$P_r(d_f)_{\substack{\text{surveillance,}\\ \text{main beam}}} = 98.2 - 20 \log d_f \quad \text{dBm/m}^2 .$$

The illumination duration of the same airborne target by the first sidelobe is about twice as great, so that the equivalent duty cycle is -23.8 dB, but the pulse power density is 20 dB below that of the main beam. Therefore, the average power density is

$$P_r(d_f)_{\substack{\text{surveillance}\\ \text{first sidelobe}}} = 81.2 - 20 \log d_f \quad \text{dBm/m}^2 .$$

which is 17 dB (a factor of 50) less than that of the main beam. The average power density of the higher-order sidelobes on the airborne target is

$$P_r(d_f)_{\substack{\text{higher-order}\\ \text{sidelobes}}} = 79.6 - 20 \log d_f \quad \text{dBm/m}^2$$

which is almost 19 dB (a factor of 80) less than that of the main beam.

The EED criteria specify that the combined power from multiple transmitters (or beams) should be used in calculating the average power density (AF Regulation 127-100). For PAVE PAWS' illumination of airborne EEDs, the combined power density of the main beam and all sidelobes is overwhelmingly contributed by the main beam, which is shown in Figure D-16. For aircraft in flight, the applicable EED criteria is 100 W/m$^2$ (10,000 microwatts/cm$^2$). Figure D-16 indicates that that level will not be exceeded even by main-beam illumination beyond the near field (600 ft). The same applies for the growth system. Table D-19 lists the separation distances.

PAVE PAWS poses no threat to the safe handling and transport of EEDs outside the exclusion fence.

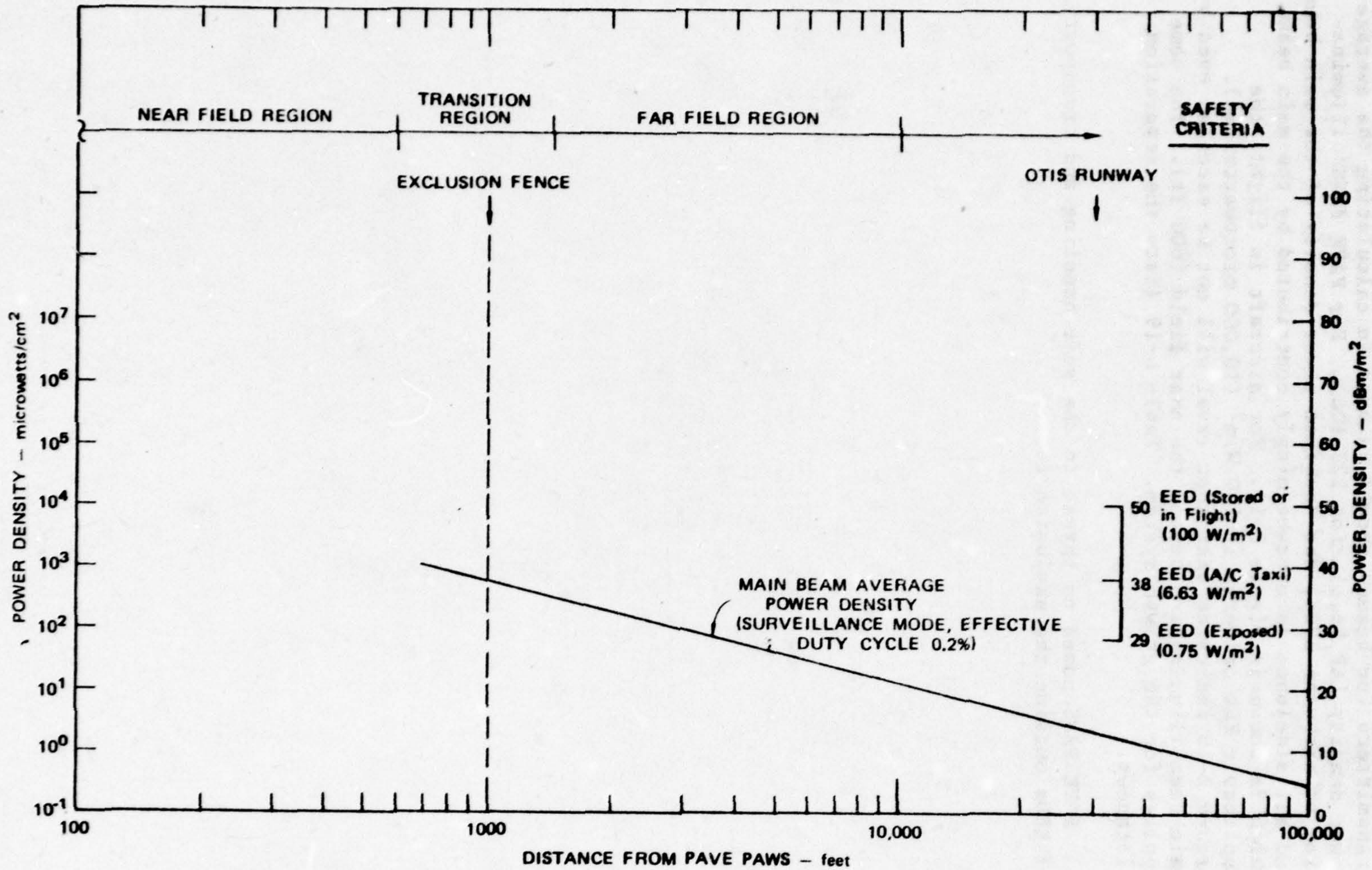


FIGURE D-16. AVERAGE POWER DENSITY FOR PAVE PAWS, BASIC SYSTEM, USING FREE SPACE PATH LOSS ++

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## Appendix E

## SOCIOECONOMIC ANALYSIS

The methodology used in this study to estimate the potential quantifiable changes likely to occur with the operation of PAVE PAWS consisted of the following four major steps:

- Preparation of a description of the existing site characteristics determined during on-site visits of each of the three Air Force installations — Otis AFB, Fort Fisher AFS, and Charleston AFS -- likely to be affected by the operation of PAVE PAWS (see Section 1.2, p. 1-7, Existing Site Characteristics).

- Preparation of a description of the socioeconomic characteristics of the communities that surround each base, particularly those communities that are related socially and/or economically to that Air Force Base (see below).

- Use of a model, which was developed previously for the Air Force as part of another study and uses about 100 inputs, some national and some local data, to calculate information on four different attributes: employment, personal income, housing, and population (Socioeconomic Impact Assessment Methodology Handbook, September 1978).

- Analysis of the outputs of the model to determine the possible socioeconomic changes likely to occur at the three sites and in their related communities (see Chapter 3).

### E.1 <u>The Environs of Otis AFB, Massachusetts</u>

This appendix presents data on employment, population, income, housing, education, health care, and tourism for Barnstable County, which includes the whole of Cape Cod; the four towns that are expected to be most affected by the influx of PAVE PAWS

personnel (Bourne, Falmouth, Mashpee, and Sandwich; see Figure 2-1, p. 2-2); and Otis Air Force Base.

### E.1.1 Employment

Table E-1 shows the 1977 labor force and unemployment rates for Barnstable County and the four towns surrounding Otis. To illustrate the extreme seasonal fluctuations in employment at Cape Cod, peak winter and low summer unemployment figures are given.

As is evident in Table E-2, p. E-4, two industries in Barnstable County employ a significant percentage of the total work force - retail trade (40.3%) and services (27.0%). Other important industries are transportation, communications, and utilities (7.1%), manufacturing (6.8%), and construction (6.3%).

An increasing number of people are expected to visit the Cape in the summer, implying that the retail trade and services sectors will continue to grow. The manufacturing share will expand if efforts to attract nonpolluting, light manufacturing industries continue to be successful. Being directly related to the area's rate of growth, the construction industry is expected to grow considerably beyond current levels, then stabilize, and finally decline, as open space on the Cape becomes less available. In the short run, however, construction employment is expected to be at or above current levels in 1995.

Local unemployment rates in 1977 were high (7-21%), reflecting the region's slow recovery from the 1975 recession. The average unemployment rate for the county was 11.3% in 1977, down from 12.5% in 1976. Unemployment rates have been declining recently, probably because the construction has boomed and more businesses are able to stay open for more months (some even year-round) as tourists respond increasingly to off-season discounts. The off-season employment picture is expected to continue to improve, as a result of the longer tourist season, and this will somewhat dampen the seasonal job fluctuation.

### E.1.2 Population

Table E-3, p. E-5, shows population data for the four potentially affected towns and Barnstable County in 1970, 1975, and projected for 1995. Both summer and winter population data are included because tourism greatly increases summer population figures.

As Table E-4, p. E-6, shows, the total winter population of Cape Cod grew at a moderately high annual rate of 6.4% between 1970 (97,000) and 1975 (128,000). Slower annual increases of about 2.4% through the winter and about 2.5% during the summer are

Table E-1

**LABOR FORCE AND UNEMPLOYMENT RATES**
**1977**

| | Winter High (January) | Summer Low (July) | Annual Average |
|---|---|---|---|
| **Bourne** | | | |
| Labor force | 5,731 | 7,311 | 6,391 |
| Unemployment rate (percent) | 17.9 | 6.9 | 10.8 |
| **Falmouth** | | | |
| Labor force | 9,968 | 1,333 | 1,145 |
| Unemployment rate (percent) | 16.9 | 4.1 | 6.5 |
| **Mashpee** | | | |
| Labor force | 600 | 681 | 622 |
| Unemployment rate (percent) | 32.7 | 14.1 | 21.2 |
| **Sandwich** | | | |
| Labor force | 2,539 | 2,999 | 2,698 |
| Unemployment rate (percent) | 27.8 | 11 5 | 17.6 |
| **Total county** | | | |
| Labor force | 54,799 | 69,510 | 60,901 |
| Unemployment rate (percent) | 18.7 | 7.2 | 11.3 |

Source: Cape Cod Planning and Economic Development Commission.

Table E-2

BARNSTABLE COUNTY EMPLOYMENT, 1977

| Industry | Employment Low | | Employment High | | Average | Percent |
|---|---|---|---|---|---|---|
| Agriculture, Forestry, and Fisheries | 294 | (Feb.) | 757 | (July) | 581 | 1.6% |
| Mining | 17 | (Jan.) | 26 | (July) | 22 | 0.1 |
| Construction | 1,679 | (Feb.) | 1,605 | (Oct.) | 2,259 | 6.3 |
| Manufacturing | 2,194 | (Apr.) | 2,594 | (Aug.) | 2,447 | 6.8 |
| Transportation, communications, and utilities | 2,240 | (Feb.) | 2,798 | (Sept.) | 2,551 | 7.1 |
| Wholesale trade | 599 | (Feb.) | 1,104 | (July) | 779 | 2.2 |
| Retail trade | 10,512 | (Feb.) | 20,395 | (Aug.) | 14,576 | 40.3 |
| Finance, insurance, and real estate | 1,764 | (Feb.) | 2,090 | (July) | 1,936 | 5.4 |
| Services | 6,489 | (Jan.) | 13,480 | (Aug.) | 9,743 | 27.0 |
| Government | 1,243 | (Feb.) | 1,348 | (June) | 1,240 | 3.4 |
| Total | 27,546 | (Feb.) | 46,761 | (Aug.) | 36,134 | 100.2%[a] |

[a]Does not add to 100% due to rounding.

Source: Massachusetts Division of Employment Security (compiled by Cape Cod Planning and Economic Development Commission).

Table E-3

**POPULATION ESTIMATES AND PROJECTIONS**

| | Winter 1970 | Winter 1975 | Summer[a] 1975 | Projected Winter 1995 | Projected Summer 1995 |
|---|---|---|---|---|---|
| Bourne[b] | 8,770 | 10,800 | 29,900 | 16,000 | 43,000 |
| Falmouth[b] | 15,820 | 20,650 | 51,200 | 31,000 | 80,000 |
| Mashpee | 1,290 | 2,490 | 14,000 | 6,000 | 22,000 |
| Sandwich[b] | 3,630 | 6,350 | 16,500 | 12,000 | 29,000 |
| Otis AFB | 5,600 | 1,800 | 3,000[c] | 2,000 | 3,000 |
| Total Cape Cod | 97,000 | 128,000 | 382,100 | 190,000 | 571,000 |

[a] Includes renter-occupied dwellings, second homes, and transient accommodations.

[b] Excludes people living on Otis AFB.

[c] Includes 1,200 National Guard "campers."

Sources: Cape Cod Planning and Economic Development Commission, "Draft Environmental Impact Statement and Proposed 208 Water Quality Management Plan for Cape Cod" (March 1978); 1970 figures based on U.S. Census of Population, Vol. PC(1)-B23 (1970); 1975 figures based on Philip B. Herr Associates estimates reflecting the number of persons actually counted, without adjustments for place of domicile; 1995 figures based on Philip B. Herr Associates projections.

Table E-4

POPULATION CHANGES IN POTENTIALLY AFFECTED AREAS,
1970, 1975, and 1995
(Percent)

| | Annual Average Change, Winter 1970-1975 | Projected Annual Average Change, Winter 1975-1995 | Projected Annual Average Change, Summer 1975-1995 |
|---|---|---|---|
| Bourne | 4.6% | 2.4% | 2.2% |
| Falmouth | 6.1 | 2.5 | 2.8 |
| Mashpee | 18.6 | 7.0 | 2.9 |
| Sandwich | 15.0 | 4.4 | 3.8 |
| Otis AFB | -13.6 | 0.5 | 0.0 |
| Total Cape Cod | 6.4 | 2.4 | 2.5 |

projected for the near future. The largest historical increases occurred in Mashpee and Sandwich between 1970 and 1975. The population of Otis Air Force Base suffered a substantial decline during this period, dropping from 5,600 to 1,800. Although the population is projected to increase at a lower rate in the future, Mashpee and Sandwich are still expected to increase at rates faster than Bourne and Falmouth and the county average.

A popular area for retirement, Barnstable County has a large proportion of older people in its year-round population. More than 21% of the winter population was over 60 years old in 1975. The retirement-age population is expected to grow at a slightly less rapid rate in the future; only 20.5% of the winter population in 1995 is expected to be over 60 years old.

Average household size of the winter population is believed to be decreasing in Barnstable County because of the increasing proportion of retirement homes on the Cape and in parallel with a national trend towards smaller families. The estimated size of a household in 1975 was 2.8, and this is projected to decrease to 2.6 by 1985 and to 2.5 by 1995 (Water Quality Management Plan/EIS for Cape Cod, 1978).

### E.1.3 Income

Total personal income in Barnstable County in 1976 was $908 million (Survey of Current Business, June 1978). Per capita

income was $6,684 in 1976, ranking Barnstable County seventh in the state.

As Table E-5 shows, services, retail trade, and government were major sources of personal income in Barnstable County in 1975. Transfer payments, which accounted for a large share (23.6%) of personal income, was the fastest growing income source, increasing by 29% between 1974 and 1975, and thus reflecting the increasing number of retired people in the county. Military earnings, however, declined substantially during this period, due to the phasing down of Air Force operations. Earnings in the construction industry hit a new low, reflecting the national and local recession, but recovered in following years. Agricultural income declined somewhat in 1975, a trend that has continued in recent years as urbanization overtakes an increasing amount of rural farmland.

## E.1.4 Housing

Housing figures for the four towns around Otis AFB are given in Table E-6, p. E-9. As expected, the largest increases in housing starts occurred in Mashpee and Sandwich, where population was growing the fastest between 1970 and 1975.

Residential building permits have also increased significantly. The greatest number of units being built are in Bourne and Sandwich, as these towns now have the largest population growth.

One local realtor (Charles Jacoby, August 1978) described the housing market as being strong in three of the four potentially affected cities. In Mashpee, however, land titles are clouded and buying or selling houses is very difficult because local Indians are suing the town (see Section 3.1.3.2.4, p. 3-83). Mr. Jacoby noted that the average selling price of new homes was about $35,000 in Bourne, $50,000 in Falmouth, and $60,000 in Sandwich. At any given time, approximately 250-300 homes are for sale on the west side of the Cape. This is a fairly constant yearly average; although most vacationers visit the Cape in summer, many wait until after their vacation to buy homes.

As a result of the scarcity of multiple unit dwellings, there is less rental housing available than there are houses for sale. Furthermore, the only reasonably priced rental units, according to the realtor, are winter-only rentals.

A slowdown in the real estate market has occurred recently because money is tight and borrowing rates are high. In addition, in Sandwich the market has become somewhat tight because a relatively large number of workers moved there when the electric power station was expanded last year.

Table E-5

**BARNSTABLE COUNTY PERSONAL INCOME BY MAJOR SOURCES**
**(Thousands of Dollars)**

| | 1975 | Percent of Total | Percent Change 1974 to 1975 |
|---|---|---|---|
| Total personal income received by county residents[a] | $738,365 | 100.0% | 10% |
| Labor and proprietors' income | 351,227 | 47.6 | 3 |
| Dividends, interest, and rent | 212,657 | 28.8 | 8 |
| Transfer payments | 174,481 | 23.6 | 29 |
| Labor and proprietors' earnings paid in county by industry[b] | 376,757 | 100.0 | 3 |
| Farm | 849 | 0.2 | -8 |
| Nonfarm | 375,908 | 99.8 | 3 |
| Private | 295,342 | 78.4 | 3 |
| Manufacturing | 19,914 | 5.3 | 6 |
| Contract construction | 24,651 | 6.5 | -24 |
| Wholesale and retail trade | 95,128 | 25.3 | 8 |
| Finance, insurance, and real estate | 19,235 | 5.1 | 6 |
| Transportation, communications, and public utilities | 31,061 | 8.2 | 8 |
| Services | 100,714 | 26.7 | 6 |
| Other industries | - | 1.3 | - |
| Government | 80,566 | 21.4 | 4 |
| Federal civilian | 28,596 | 7.6 | 5 |
| Federal military | 3,459 | 0.9 | -29 |
| State and local | 48,511 | 12.9 | 8 |
| Per capita income | 5,696 | - | 5 |

[a]This category includes income from all sources, measured after deduction of personal contributions to Social Security, government retirement, and other social insurance programs, but before deduction of income and other personal taxes. Income earned in the county by nonresidents is excluded. "Proprietors' income" is the net business earnings of owners of unincorporated enterprises, such as farmers and independent professionals. "Transfer payments" are income from government and business for which no services are currently rendered (including benefits from social insurance and retirement programs).

[b]Income derived from employment in mining and other industries is not itemized to avoid disclosure of confidential information, but this income is included in totals.

Source: Regional Economics Information System, Bureau of Economic Analysis, U.S. Department of Commerce (compiled by Cape Cod Planning and Economic Development Commission).

Table E-6

TOTAL HOUSING UNITS, 1970 and 1975[a]

| | 1970 | 1975 | Percent Change, 1970 to 1975 |
|---|---|---|---|
| Bourne | 5,027 | 6,100 | 4.3% |
| Falmouth | 9,587 | 11,900 | 4.8 |
| Mashpee | 1,991 | 2,900 | 9.1 |
| Sandwich | 2,197 | 3,200 | 9.1 |
| Total | 18,802 | 24,100 | 5.6% |

[a]Excludes units at Otis AFB.

Source: Cape Cod Planning and Economic Development Commission, "Draft Environmental Impact Statement and Proposed 208 Water Quality Management Plan for Cape Cod" (March 1978); 1970 figures from U.S. Census of Housing, Vol. 1, part 23 (1970); 1975 figures from Philip B. Herr Associates estimates based on residential construction data.

## E.1.5 Education

### E.1.5.1 Bourne

Bourne is currently served by one high school, two junior high schools, and five elementary schools. Three of these schools -- Stone and Otis Memorial Elementary Schools and Lyle Junior High School -- are on Otis AFB. A fourth school, now closed, is also situated on the base.

As of 18 September 1978, 2,811 students were registered with the Bourne School Department (Brown, 1978). The 1978-79 enrollment represents a decline of 175 students, or 5.8%, from the 1977-78 enrollment of 2,986 students (see Table E-7). That statistic, however, is misleading, because the Mashpee School Department used to send approximately 100 students to Lyle Junior High School. With the completion this summer of the new Mashpee Middle School, seventh- and eighth-graders in Mashpee can now attend school there. Thus, the change in enrollment caused by actual changes in the population of Bourne is closer to a decline of 75.

The Bourne schools have a current capacity of 3,725 pupils, with approximately 900 spaces open. Bourne High School, however,

Table E-7

SCHOOL ENROLLMENT BY SCHOOL SYSTEM, 1976-77, 1977-78

| | 1976-77 | 1977-78 | Percent Change 1976-77 to 1977-78 | 1978-79 |
|---|---|---|---|---|
| Bourne[a] | 3,044 | 2,986 | -1.9% | 2,811 |
| Falmouth[b] | 5,340 | 5,118 | -4.2 | 5,002 |
| Mashpee[c] | 365 | 375 | 2.7 | 485 |
| Sandwich | 1,538 | 1,686 | 9.6 | 1,830 |
| County | 27,902 | 27,547 | -1.3 | NA[d] |

[a]Includes Mashpee students attending Lyle Jr. High School in Bourne.

[b]Includes Mashpee students attending Falmouth High School.

[c]Includes only elementary school.

[d]Not available.

has a near-capacity enrollment of 847 students (capacity is 850). The two junior high schools, Lyle and Coady, have a combined capacity of 700 students, with 601 currently enrolled. Capacity at the elementary level is 2,275 students; at present, enrollment in grades K-6 is 1,495. An additional 350 elementary school students could be accommodated by the Campbell School, the closed facility on Otis AFB. Opening that school would be expensive, however, because much of its equipment was moved to other schools in Bourne when Campbell was closed. The equipment was not surplus; it was needed by other schools, and the school department would probably have to purchase new materials if Campbell were to be reopened.

Of the Bourne School Department's total 1978-79 enrollment, 551 pupils are the children of military personnel who reside on Otis AFB. Current data are not available on the number of pupils whose parents are stationed at Otis but live off-base (the figure for 1977-78 was 35 pupils).

Nearly $1.1 million of the Bourne School Department's 1978-79 budget is being furnished by the federal government under Public

Law 874. The government's contribution is nearly 19.3% of the total school budget of more than $5.6 million.

### E.1.5.2 Sandwich

Student populations grew by nearly 8% this fall in the already crowded Sandwich public schools. The elementary school, with 950 pupils, currently has 50 pupils over its intended capacity. The number of students at Sandwich High School increased by 10% in 1978 over the enrollment for 1977-78. School officials expect that enrollment in the high school will increase from the present 880 to the facility's capacity of 1,000 students by autumn of 1979 (Sibson, personal communication, September 1978).

As of 1 October 1977, the parents of 130 pupils in the Sandwich schools were employed by the federal government in both civilian and military service. Monies allocated to the Sandwich School Department under PL 874 totaled $21,000, approximately 1% of the total school budget of $2 million.

### E.1.5.3 Mashpee

Enrollment in the Mashpee School Department increased by less than 1% between 1977-78 and 1978-79 (Annual Report, Town of Mashpee, 1977; Miller, 1978). The recent Indian litigation, which has clouded claims to title on real estate in Mashpee, has discouraged families from moving to the town. Between 1972 and 1977, however, enrollment in Mashpee increased by 58%, including the junior and senior high school students who attended schools in Bourne and Falmouth.

As of September 1978, all of the approximately 485 pupils in grades K-8 began attending the Mashpee Middle School, completed this summer and has a capacity of 600 pupils. The construction of the new school enabled the school department to accommodate its seventh- and eighth-grade students, who had previously been sent to Lyle Junior High School on Otis AFB.

Mashpee students in grades 9-12 attend Falmouth High School in Falmouth. This year, Mashpee is sending approximately 178 students to Falmouth, at a cost to the Mashpee School Department of $1,650 per pupil (Johnson and Miller, September 1978).

In 1977-78, 29 Mashpee students had parents who were stationed at Otis AFB (Miller, September 1978). Funds granted the school department under PL 874 amounted to $2,990, or approximately 0.2% of the department's budget of about $1.35 million. As of September 1978, the school department had not conducted its survey of military-related children in the Mashpee schools for the 1978-79 school year.

E.1.5.4 Falmouth

Enrollment in the Falmouth schools has decreased by about 8.5% between the 1975-76 school year and September 1978. Pupils in grades K-12 in 1978 number 5,002, including approximately 178 high school pupils from Mashpee and 1 special-needs pupil from Bourne. In the 1975-76 academic year, 5,463 students were attending school in Falmouth (Barnstable County School Department, 1978). According to a school official, enrollment in Falmouth was once about 5,800 students (Johnson, 1978).

Excess capacity is greatest at the primary grade level. Falmouth's five K-4 schools have a rated capacity of 2,260 students and a recommended capacity of 1,890. (The smaller limits were recommended earlier this year by a local citizen's advisory committee on elementary education. At present, all the Falmouth schools for children in grades K-8 have enrollments below the recommended capacities.)

The three schools for pupils in the remaining grades offer less space for new students than the primary schools do. Morse Pond School (grades 5-6), with a rated capacity of 875 and a recommended limit of 750, currently holds 723 students. Lawrence School (grades 7-8) is approaching its rated capacity of 909 students and its recommended capacity of 900; 878 pupils are currently enrolled there. Falmouth High School, with 1,715 students, has a capacity of 1,800 pupils.

Of the total 1978-79 enrollment, 366 students are eligible for federal assistance under PL 874. The Falmouth School Department expects to have $154,000 of PL 874 monies for the 1978-1979 budget; all but $63,000 of that amount is currently on hand. If the $63,000 is actually appropriated, PL 874 funds will be approximately 1.7% of the Falmouth school budget of about $9.25 million.

E.1.6 Health Care Facilities

Falmouth Hospital in Falmouth, Cape Cod Hospital in Hyannis, Jordan Hospital in Plymouth, and Tobey Hospital in Wareham are the four local civilian hospitals most used by Otis personnel and their families. The number of hospital beds and annual occupancy rates for each of these hospitals is shown in Table E-8. Falmouth Hospital is the closest to the Base, and, therefore, the military probably uses it most often.

Bourne has two physicians, Falmouth and Mashpee have a total of about 32, and Sandwich has only one practicing physician. Local nursing associations compensate for the shortage of doctors in these areas.

Table E-8

**NUMBER OF BEDS AND ANNUAL OCCUPANCY RATES FOR HOSPITALS IN POTENTIALLY AFFECTED AREAS, 1976**

| Hospital | Location | Number of Beds | Average Annual Occupancy Rate (Percent) |
|---|---|---|---|
| Falmouth Hospital | Falmouth | 88 | 77.3% |
| Cape Cod Hospital | Hyannis | 270 | 84.4 |
| Jordan Hospital | Plymouth | 131 | 81.7 |
| Tobey Hospital | Wareham | 89 | 66.3 |

Source: American Hospital Association, Guide to the Health Care Field (1977).

Other health care facilities are available; however, rooms in retirement homes are in short supply. A large mental health clinic in Bourne can handle additional patients.

### E.1.7 Tourism

Tourists spent more than 11.3 million visitor-days in Barnstable County in 1976. Their expenditures on meals, hotel rooms, entertainment, and the like totaled more than $2.7 million. Business peaked during the summer (July-September), when more than 6 million visitor-days were recorded in the county. Winter was the slowest time of the year, with 1.2 million visitor days (Cornouyer and Kindahl, 1977).

About 455,000 people are on the Cape on any day between July 15 and August 15. The number includes 130,000 year-round residents, 240,000 seasonal residents, 70,000 people staying in public accommodations, and 15,000 day visitors (Frucci, 1978).

## E.2 The Environs of Fort Fisher AFS, North Carolina

### E.2.1 Employment

Wilmington is the regional trade center for southeastern North Carolina, and so is an important area of economic activity in the state. New Hanover County experienced an economic boom in the

late 1960s and early 1970s. The county's economy declined during the recession in 1973-74, but has been recovering steadily since. Many companies have been moving into the Wilmington area since 1975, contributing to the recent economic growth of the area, although the influx has slowed since 1977. Sectors with the largest percentage of total employment in the county are manufacturing (25%), trade (20%), government (12.5%), and services (about 10%) (Lilley, 1978).

Statistics on the labor force, employment levels, and the rates of unemployment for the Wilmington SMSA (which consists of Brunswick and New Hanover County) are shown in Table E-9.

### E.2.2 Population

Population in the county increased by 2.5% annually between 1976-1978, and it is expected that this rate of growth will continue. Population changes for the City of Wilmington and New Hanover County are shown in Table E-10.

Table E-9

HISTORICAL EMPLOYMENT LEVELS AND UNEMPLOYMENT RATES, WILMINGTON SMSA[a]

| Wilmington SMSA | 1975[b] | 1976[b] | 1977[b] | March 1978[c] | Percent Change 1975-76 | Percent Change 1976-77 |
|---|---|---|---|---|---|---|
| Civilian Labor Force | 55,420 | 56,700 | 56,810 | 56,760 | 2.3 | 0.2 |
| Total Employment | 50,700 | 52,190 | 52,250 | 53,360 | 2.9 | 0.1 |
| Unemployment Rate | 8.5% | 8.0% | 8.0% | 6.0% | -5.9 | 0.0 |

[a]Standard Metropolitan Statistical Area.

[b]Source: "Community Profile, Greater Wilmington Area," 1978 Edition.

[c]Outland, 1978.

Table E-10

HISTORICAL POPULATION LEVELS, CITY OF WILMINGTON AND NEW HANOVER COUNTY

| Area | 1970[a] | 1976[a] | Preliminary July 1, 1978[a] | Average Annual Percent Growth Rate 1970-1976 | Average Annual Percent Growth Rate 1976-1978 |
|---|---|---|---|---|---|
| Wilmington | 46,169 | 52,390 | NA[b] | 2.0 | NA[b] |
| New Hanover County | 82,996 | 96,100 | 101,200 | 2.3 | 2.5 |

[a]Greater Wilmington Chamber of Commerce, 1978.

[b]Not available.

### E.2.3 Income

Total personal income for the county was $534 million in 1976, with a per capita figure of $5,560. New Hanover County ranks 21st in the state in per capita income.

### E.2.4 Housing

The housing market in New Hanover County was described as weak by Air Force personnel. A study by the Federal Home Loan Bank showed vacancy rates of 4.4% for houses and apartments in January, 1978, in the Wilmington SMSA. A private survey of apartment buildings in Wilmington showed a vacancy rate of 14% for apartments, out of a total of 3,174 units in May, 1978 (Harbour Associates). Air Force personnel estimated that between 350 and 450 houses are for sale at any time.

### E.2.5 Education

The New Hanover County Public School System has 32 schools (Greater Wilmington Chamber of Commerce, 1978). Enrollment in county public schools increased rapidly in the early 1970s, but has been leveling off in recent years (Mason, 1978) because of a lower number of school-aged children in the county. This is because industries are not moving into the area at as great a rate

as in the past, and because of a general trend toward smaller family sizes. Enrollment in the New Hanover County schools declined by 1.3% from 21,188 in September 1977 to 20,912 in September 1978.

Before a recent school reorganization, some schools in the county were operating above their capacity (Mason, 1978). At present, the school system is described as approaching capacity, with the ability to accommodate small increases in student population in the future.

In 1977, there were approximately 400 military-related students in the district, of which about 40 were from personnel stationed at Fort Fisher. The County's PL 874 fund entitlement was $237,713, or less than 0.8% of a total school budget of $30,791,802 in 1977 (Howie, 1978).

### E.2.6 Health Care

Wilmington has the New Hanover Memorial Hospital, with 419 beds and an 85.9% occupancy rate, and the Cape Fear Memorial Hospital, with 99 beds and a 75.7% occupancy rate. Both hospitals are undergoing expansion programs that will increase the number of beds to 527 and 111 beds, respectively (The American Guide to the Health Care Field, 1977).

Wilmington is considered to be the health care center of southeast North Carolina. This has led to a shortage of beds in both of the city hospitals, which the expansion program is designed to alleviate (Davis, 1978).

There are 150 licensed practicing physicians in the greater Wilmington area, or 1.6 physicians per thousand people in the county. In addition, there is a a mental health center with a staff of 75 employees in Wilmington.

## E.3 The Environs of Charleston AFS, Maine

Penobscot County, one of the largest and most populous counties in Maine, is a manufacturing center as well as recreation area. Bangor is the largest city in the county and the third largest city in the state. Most of the expenditures of Charleston AFS personnel are made either in Bangor or at Dow Air Force Base. Dover-Foxcroft, in Piscataquis County, also benefits economically from the Station. Little money is spent by personnel in the immediate vicinity of the Station (i.e., in the towns of Charleston and East Corinth).

### E.3.1 Employment

During one month in 1975, the Southwest Penobscot labor market area, which includes Charleston AFS but not Bangor, had an unemployment rate of 19.3% resulting from the closing of two major manufacturing firms. Unemployment in the area had been high (more than 10%) since 1970; the average for 1975 was 14.9%. In 1977 the unemployment rate was 15.7% -- 1,019 were unemployed and 5,463 were employed. During 1977, 8.2% of the civilian labor force of Penobscot County as a whole, or approximately 4,900 persons were unemployed (the unemployment rate for the State of Maine was the same). In other words, 55,200 of the total labor force of 60,100 were employed.

In the Bangor area, the majority of employees held jobs in government, wholesale and retail trade, services, and other non-manufacturing activities. The unemployment rate in Bangor was 7.6% in 1977.

Early in 1975, the unemployment rate in Piscataquis County was 16.1% as a result of the closing of three companies in Dover-Foxcroft and five others in the county during 1973 and 1974. The average annual unemployment rate was 10.8% in 1975 and 8.5% in 1977. In an attempt to alleviate the problems arising from high unemployment, the Eastern Maine Development District has designed an economic adjustment strategy and will encourage the development of certain industries.

### E.3.2 Population

In 1975, the population of Penobscot County was 133,671, that of Bangor was 32,262, and that of Dover-Foxcroft was 4,051. Charleston and Corinth had 1,189 and 1,382 people, respectively. Estimated 1978 populations were 138,475 for Penobscot County and 33,910 for Bangor (these estimates have not been verified). Population growth in the smaller towns was not expected to be, and has not been, significant. The 1977 population estimates were 4,140 for Dover-Foxcroft, 1,250 for Charleston, and 1,430 for Corinth.

### E.3.3 Income

Total personal income in Penobscot County in 1976 was $693 million, and per capita income was $5,107 (Survey of Current Business, June 1978). Per capita income in Bangor in 1974 was estimated at $3,718, and individual gross wages were estimated at $8,573. Per capita income in Dover-Foxcroft was comparable to that in Bangor; however, in Charleston, it was estimated at $3,117 for 1974, and in Corinth, at $2,657.

### E.3.4 Housing

In 1975, the Penobscot Valley Regional Planning Commission conducted a survey of housing in its various subregions. According to the report, the Greater Bangor Area has the largest housing deficit in the region (2,442 units). The City of Bangor had a total of 10,450 households in 1975. Dover-Foxcroft also has a deficit of available housing units. (The survey data actually show a surplus of livable housing units there; however, these units are probably second homes -- Dover-Foxcroft is a seasonal recreational area -- and would not be available to meet local year-round demand.) The survey also shows that Dover-Foxcroft (with a total of 1,420 households) has many substandard housing units that need to be rehabilitated. Projections by the Maine State Planning Office for the number of households in 1977 were: the county as a whole, 42,815; Bangor, 10,760; Dover-Foxcroft, 1,470; Corinth, 450; and Charleston, 340.

In 1978, the City of Bangor had an estimated vacancy rate of 4.0% in all standard units; 4.4% in owner-occupied units, and 3.6% vacancy rate in renter-occupied units. The total housing stock was 11,992, of which 9,676 units were standard units (Survey of Housing Conditions, 1978, Table 1).

### E.3.5 Education

Bangor currently (1978) operates nine elementary schools, three junior high schools, and one high school, as well as a Headstart Center. Charleston has one elementary school.

### E.3.6 Health Care

Bangor has five hospitals:

(1) City Hospital, Bangor International Airport (51 beds).

(2) Bangor Mental Health Institute (355 beds, 87.8% occupancy rate).

(3) Eastern Maine Medical Center (394 beds, 80.7% occupancy rate).

(4) James A. Taylor Osteopathic Hospital (101 beds, 62.0% occupancy rate).

(5) St. Joseph Hospital (130 beds, 73.1% occupancy rate).

Bangor also has 16 clinics and 6 nursing homes. Mayo Memorial Hospital in Dover-Foxcroft has 31 beds and an occupancy rate of 55.2%.

## E.4 References

References for Appendix E are included in Chapter 10.